3.3.1.2.4 Silicon Tracker

In combination with the Superconducting Cryomagnet, the Silicon Tracker represents the centerpiece of the AMS-02 suite of detectors. The Tracker (Figure 3.3.1.2.4-1) consists of eight layers of double-sided silicon micro-strip detectors (ladders) on five support planes. The spatial resolution will be better than 10 µm in the magnet's bending plane and 30 µm perpendicular to that. The planes are placed inside the bore of the magnet, with the six innermost combined to build pairs. The two outermost layers serve as the entrance and outlet windows. All eight tracker planes together comprise 192 silicon ladders corresponding to an active area of about 6 m^2 of silicon and 200,000 readout channels. The entire tracker electronics consume 800 W of power.

The Tracker mounts at eight attach locations (4 at the top, 4 at the bottom) to the Vacuum Case conical flanges.

The three inner planes are ≈ 3.6 ft (1.1 m) in diameter and the top and bottom planes are a ≈ 4.9 ft (1.5 m) in diameter. The Tracker is ≈ 3.9 ft (1.2 m) high and weighs ≈ 438 lbs (198.5 kg).

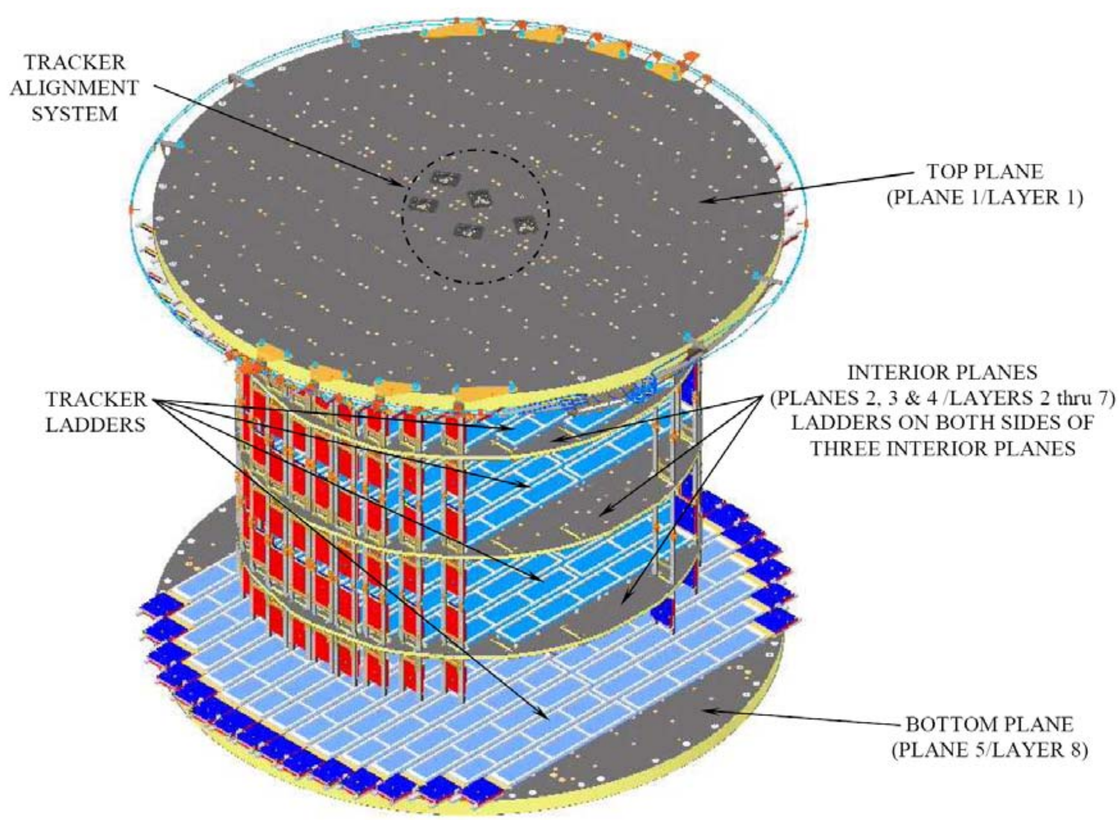


Figure 3.3.1.2.4-1 Layout of the AMS-02 Silicon Tracker

The AMS experiment silicon detector assemblies (Figure 3.3.1.2.4-2) contain silicon ladders made up of a series of 2.836 inches (72.045 mm) x 1.628 inches (41.360 mm) x 0.012 inches (0.300 mm) double-sided silicon micro-strip sensors, electrically connected by microbonds. The silicon sensors are reinforced by sandwich structures made of a 0.2 inch (5 mm) thick Airex foam with light-weight 100 µm thick layer of carbon fiber composite backing. Hybrid boards at the ends of the ladders enable the sensors to be electrically connected to the tracker electronics. The ladder assemblies vary in length from ≈ 11.47 inches (290 mm) to ≈ 40.75 inches (1035 mm), and are 2.836 inches (72.045 mm) wide and ≈ .394 inches (10 mm) thick. Thin-film, 50 µm Upilex (an ultra-high heat-resistant polyimide film) is used extensively in the ladder. A metalized Upilex film, glued directly to the silicon sensors, serves as a routing cable to bring the n-side signals to the n-side front end hybrid, which is located at the ladder end closest to the magnet wall. The flexible Upilex film and a second short Upilex film joining the p-side strips to their hybrid allow the hybrids to be placed back-to-back, perpendicular to the detection plane, thus minimizing the material in the sensitive region of the tracker. Finally, an electromagnetic shield in the form of a doubly-metalized Upilex film surrounds each ladder.

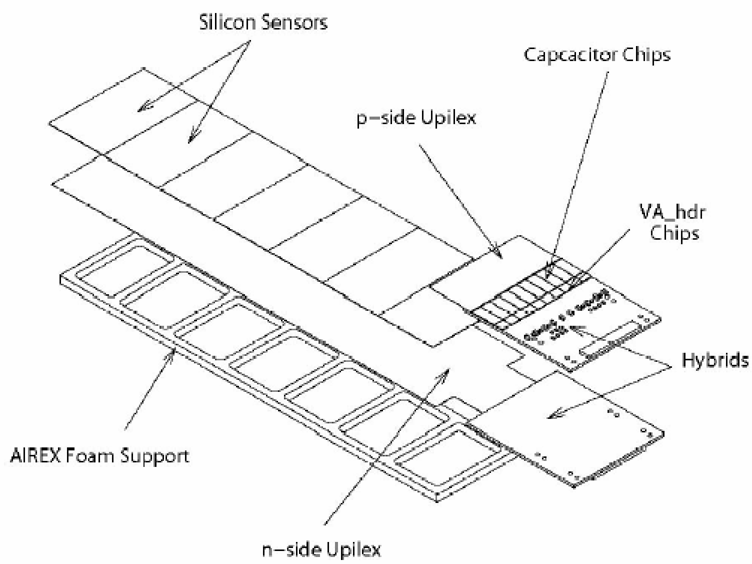


Figure 3.3.1.2.4-2 The principle components of the Silicon Ladder

Small (5 mm^3) 7075 aluminum support feet are glued to the carbon fiber surface; the exact number depends on the ladder length. The feet contain screw fixation holes which are used to attach the ladder to its tracker plane.

The tracker support structure is divided into three sections: a carbon fiber cylindrical shell which supports the planes 2 to 4 located inside the magnet, and two carbon fiber flanges which support the exterior planes 1 and 5. They have a composite structure with two 220 (700) µm thick layers of carbon fiber surrounding a 12 (40) mm thick, low density aluminum honeycomb interior, ρ =

16.02 (32.0) kg/m^3. The diameter of the interior (exterior) planes is 1.0 (1.4) m. In view of the marginal increase of the plane hermeticity, and the very significant complication of the mechanical design, there is no overlap between the ladders in the planes of the tracker. To equalize the pressure inside the Tracker with the pressure in the payload bay during launch and landing, the Upper and Lower Conical Flanges each contain two light tight, filtered vents that permit air to exit or enter the enclosed Tracker volume of 40.26 ft^3 (1.14 m^3).

The Tracker Support Planes, Cylindrical Shell, and Conical Flanges are fabricated from M55J Fiber/Cyanate Ester Composite face sheet with a Hexcell Composite Honeycomb Core. The Tracker Support Feet are made from Titanium Ti6AlV4.

3.3.1.2.5 Anti-Coincidence Counters (ACC)

The ACC is a single layer of scintillating panels that surround the AMS-02 Silicon Tracker inside the inner bore of the superconducting magnet (Figure 3.3.1.2.5-1). The ACC identifies particles that enter or exit the Tracker through the side, detecting particles that have not cleanly traversed the Tracker. The ACC provides a means of rejecting particles that may confuse the charge determination if they leave "hits" in the Tracker close to the tracks of interest.

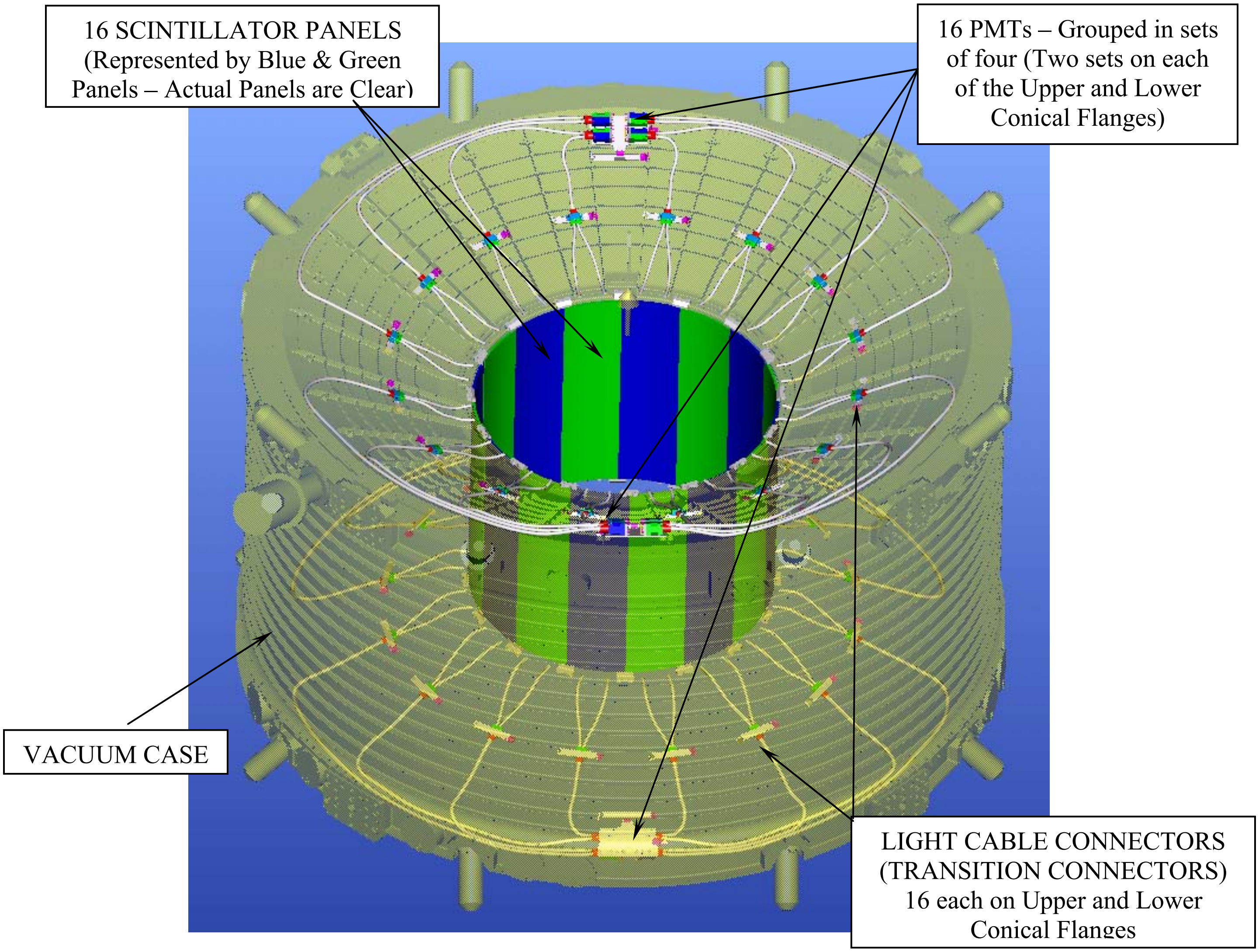


Figure 3.3.1.2.5-1 ACC Location Within the Inner Cylinder of the Vacuum Case

The ACC scintillating panels are fitted between the Tracker shell and the inner cylinder of the Vacuum Case, which contains the Cryomagnet system. The ACC is composed of sixteen interlocking panels fabricated from BICRON BC414. The panels are 8 mm thick and are milled with tongue and groove interfaces along their vertical edges to connect adjacent panels. This provides hermetic coverage for the ACC detection function around the Silicon Tracker. The panels are supported by a 33.46 in (850 mm) tall x .78 in (1086.7) diameter x 0.047 in (1.2 mm) thick M40J/CE Carbon Fiber Composite (CFC) Support Cylinder.

The light of scintillation from particles passing through the panels are collected by 1 mm wavelength shifter fibers (Kuraray Y-11(200)M) that are embedded in groves milled into the panel surface. A panel has two collection arrays, each consisting of 37 fibers. The embedded fibers are collected into 2 output ports of 37 fibers each at both ends of the panel. For each panel there are two transition connectors, one each located on the upper and lower conical flanges of the Vacuum Case. From these transition connectors the light is routed through clear fibers up to PMTs mounted on the rim of the Vacuum Case (Figure 3.3.1.2.5-2).

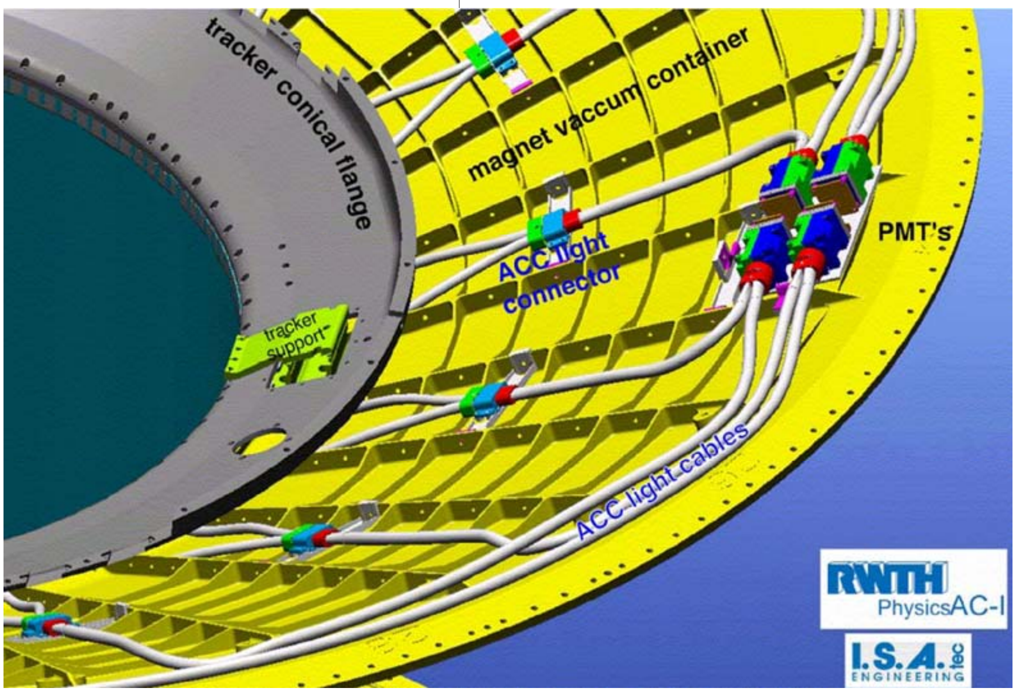


Figure 3.3.1.2.5-2 Routing of the Fiber Optic Cables from the ACC Scintillating Panels through the Transition Connectors to the PMTs

The PMTs that record the light signals from the ACC panels are identical to the PMTs used in the TOF system (Hamamatsu R5946). To minimize the impact of the magnetic field on the function of the PMTs, the PMTs are oriented with their axes parallel to the stray magnetic field.

The ACC also utilizes the same avionics architecture as the TOF to detect and interpret the passage of particles through the scintillating panels. Cables from the ACC PMTs are routed out from under the MLI covering the conical flanges to high voltage sources the S-Crate.

3.3.1.2.6 Tracker Alignment System (TAS)

The Tracker Alignment System (TAS) provides optically generated signals in the 8 layers of the silicon tracker that mimic straight (infinite rigidity) tracks of particles. These artificial straight tracks allow the tracing of changes of the tracker geometry with a position (angular) accuracy of better than 5 µm (2 µrad). The system (Figure 3.3.1.2.6-1) uses the same silicon sensors for both particle detection and control of the alignment. It serves to generate position control data within seconds at regular time intervals (4 to 6 times per orbit), for example, while the ISS flies into the shadow of the Earth or comes back into the sunlight.

The AMS-02 tracker is equipped with 2 x 10 pairs of alignment control beams. The beams are narrow (diameter < 0.5 mm) and of small divergence (< 1 mrad). The TAS generates laser energy from ten independent laser diodes, pairs of the diodes contained within five Laser Fiber Coupler (LFCR) boxes. This energy is generated by Eagleyard EYP-RWL-1083 infrared (1083 nm) laser diodes with a maximum power output of 80 mW. Each laser will emit at a 1 Hz interval with a 4 µs pulse duration when operating. Each laser diode's emissions are split into four output mono-mode optical fibers, each with approximately one quarter of the total power output. The LFCR boxes are light tight and cannot release any laser emissions with the exception of the fiber ports where laser emissions are nominal design features.

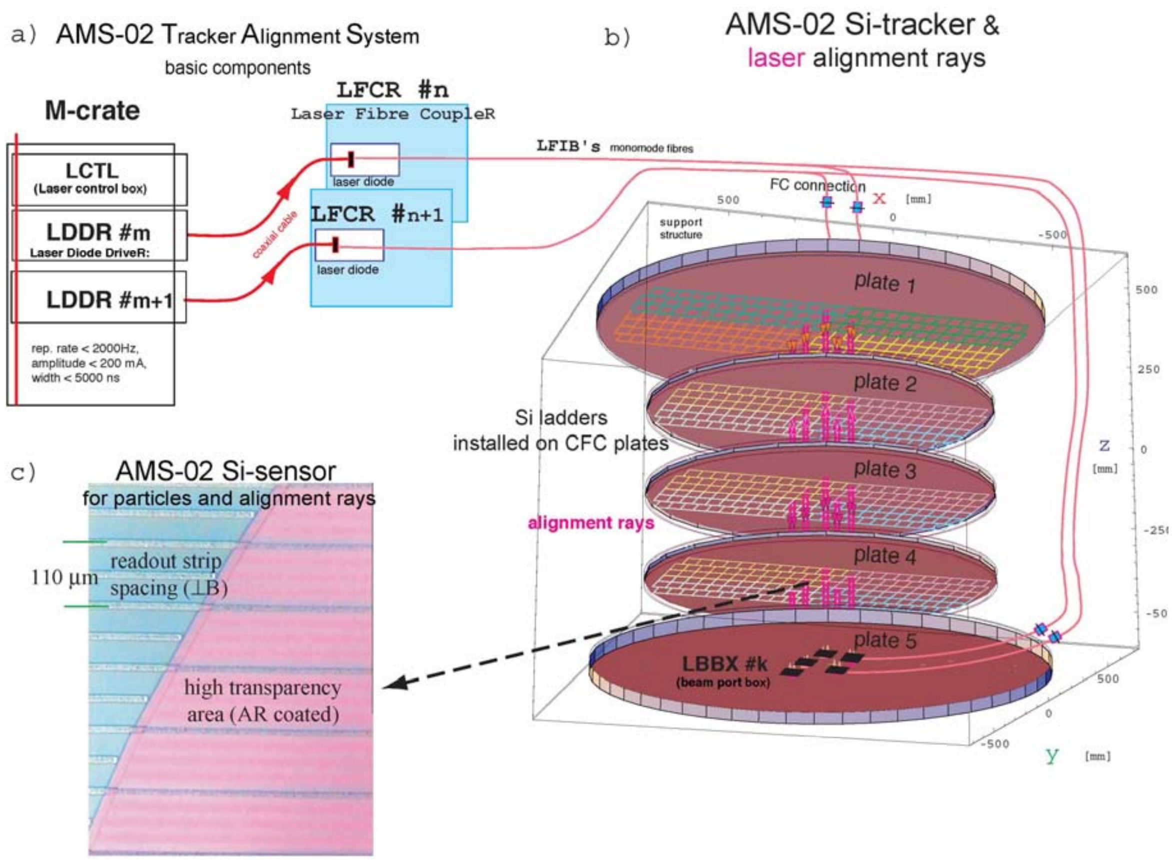


Figure 3.3.1.2.6-1 Tracker Alignment System Functional Diagram

The beams enter the tracker volume through 2 x 5 beamport boxes (LBBX) mounted on the outer face of the two outer tracker support plates. The tracker sensors on the alignment beams are equipped with antireflective coatings (SiO_2 and Si_3N_4) optimized for the wavelength chosen (residual reflectivity ~ 1%). In addition, the readout strip metallization width was reduced to 10 µm width in the coated areas and the other implants not metallized. Together these measures have resulted in a transparency of the alignment sensors of 50% and the 8th layer of the tracker receives about 0.8% of the intensity coming out of the LBBX. Alignment beams are arranged in pairs in order to distinguish between changes in beam geometry and sensor displacements. Laser alignment will be performed coincident with data taking. The operation of the TAS consists of less than 1% of the AMS-02 operational time.

3.3.1.2.7 Ring Imaging Cerenkov Counter (RICH)

The RICH is located near the bottom of the experiment stack, below the Lower TOF and above the ECAL. The RICH is used in conjunction with the Silicon Tracker to establish the mass of particles that traverse the AMS-02. The function of the Silicon Tracker is capable of establishing the momentum of the particle with a relative accuracy of approximately 1%. The RICH is able to determine the velocity of charged particles based on the Cerenkov Effect as the particle passes through the mass of the silica aerogel or sodium fluoride blocks. Cerenkov radiation is emitted as a charged particle passes through a transparent non-conducting material at a speed greater than the speed of light in that material. The use of a high efficiency reflector ring allows for greater data acquisition than direct incident of the photons on the PMTs alone.

Functionally the RICH (Figure 3.3.1.2.7-1) is composed of three basic elements, the top layer, the Cerenkov radiator, is composed of silica aerogel and sodium fluoride (NaF) blocks that serve as sources for the Cerenkov radiation generated by the passage of the high energy particles. The intermediate layer is the conical mirror and the lower the PMT and structural interfaces.

In the top layer the aerogel and NaF blocks are mounted between a PORON spacer and carpet and a PMMA cover, all supported by a carbon fiber reinforced composite (CFRC) structure (Figure 3.3.1.2.7-2). The entire structure is sealed with a viton gasket between the PMMA cover and the composite structure. The PMMA cover allows the photons generated by the passage of the high-energy particles to be observed by the photomultipliers. Polymethylmethacrylate (PMMA, Acrylic, Plexiglas) is used to contain the aerogel and crystalline NaF blocks and allow the photons to enter the zone of the conical mirror and the PMTs.

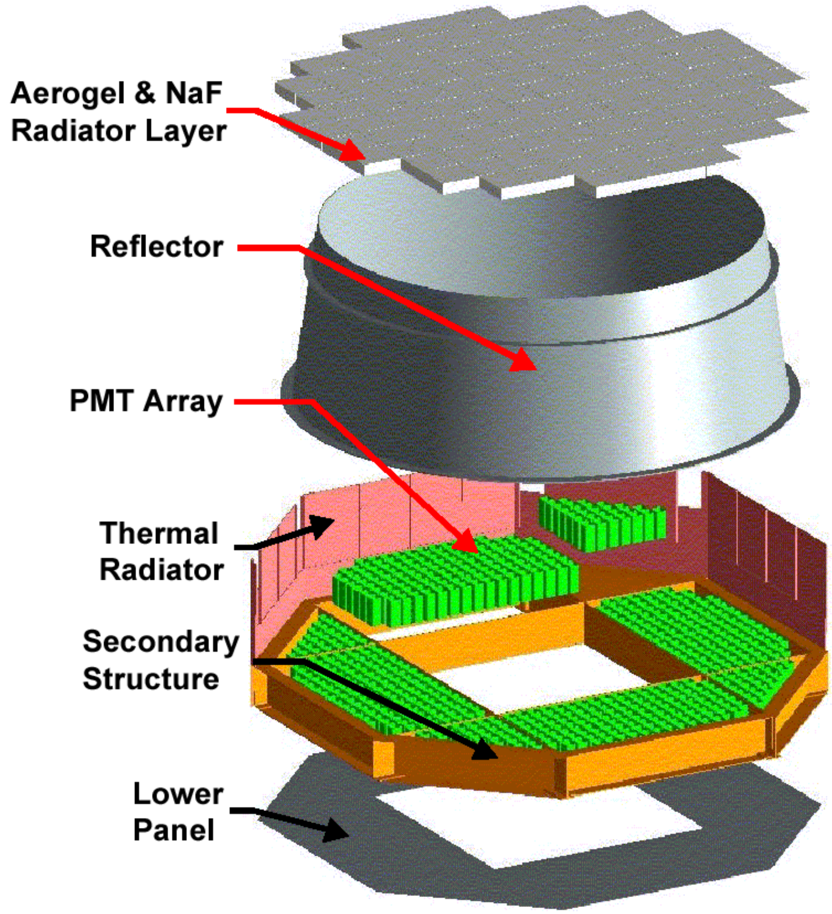


Figure 3.3.1.2.7-1 RICH Basic Elements

The RICH upper assembly of aerogel and NaF blocks is vented during ascent by four vent valves and during descent repressurization is controlled by three vent valves. In order to protect this volume once constructed it will be purged through a dedicated valve port with dry nitrogen to provide a clean controlled environment within the Cerenkov Radiator. 50 µm filter screens on the valves will prevent large aerogel or NaF particles that could possible evolve from being released or exterior contaminants becoming ingested. These valves will be Halkey Roberts C770RP 1.0 one way valves that have a cracking pressure with a 1 psi differential. The valves will be interfaced to the 50 µm filter screens through a polyetheretherketone (PEEK) interface block as shown in Figure 3.3.1.2.7-2. During ground handling/transportation and processing this interior volume is protected from thermal and atmospheric pressure variation introducing humidity into the interior of the Cerenkov Radiator by having a buffer volume contained within an expandable reservoir (0.5 l) made of Teflon®/Tedlar® supported within a vented enclosure (Figure 3.3.1.2.7-3). Design of this assembly assures that there will not be more than a 1 psi differential between the interior and exterior pressure. Reentry loads of pressure loading on the aerogel during repressurization have been conservatively established to be approximately 1/15th of aerogel compression allowable. The aerogel is considered the most sensitive element of the sandwich of materials.

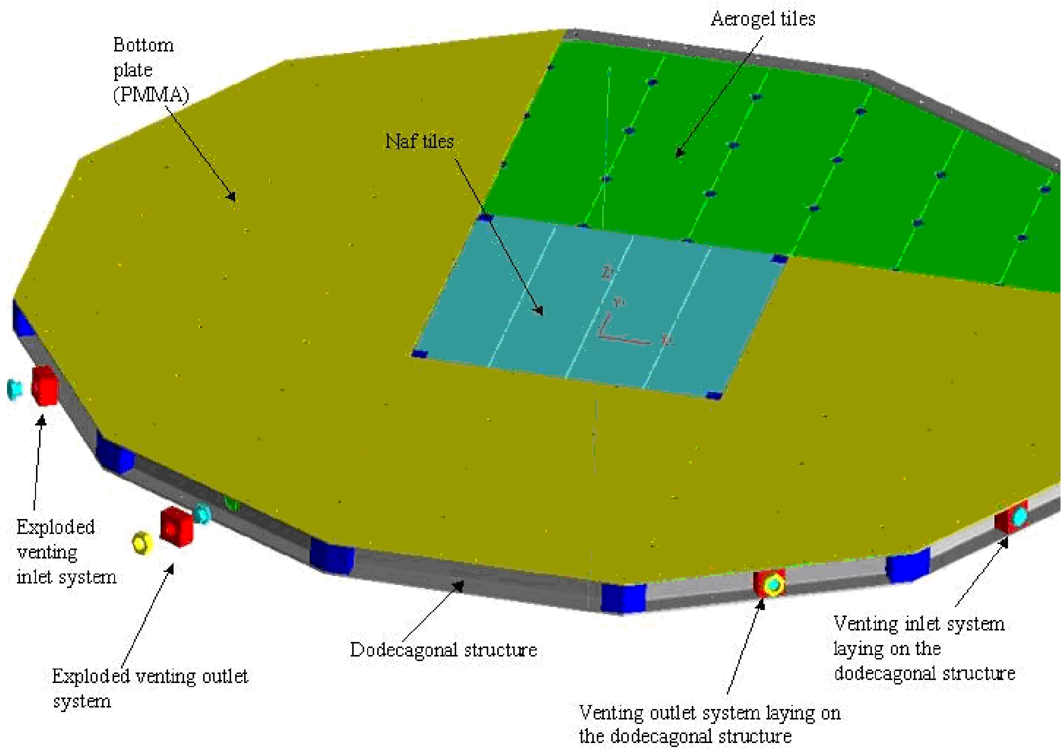


Figure 3.3.1.2.7-2 RICH Aerogel and NaF Assembly

(Vent interface updated below)

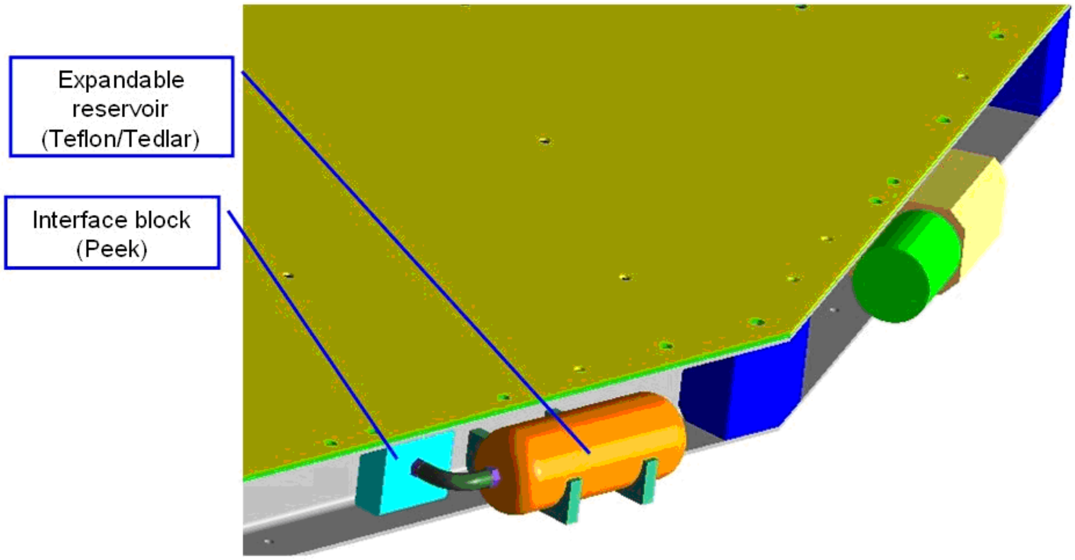


Figure 3.3.1.2.7-3 RICH Expandable Reservoir

The second layer of the RICH is a reflector that is shaped as a truncated cone, described by a trapezoid rotated about its centroid. The interior surface of this element is a highly polished composite/metal mirror. The mirror is manufactured in three pieces (Figure 3.3.1.2.7-4) to be very light and have a precise, highly reflective, surface. The reflector is made of composite material with layers of deposited gold, alumina, chromium, and quartz. A debris shield consisting of eight aluminum panels surround the reflector to protect it from penetrations that would damage the mirrored surface and allow light to enter the RICH and disturb detection.

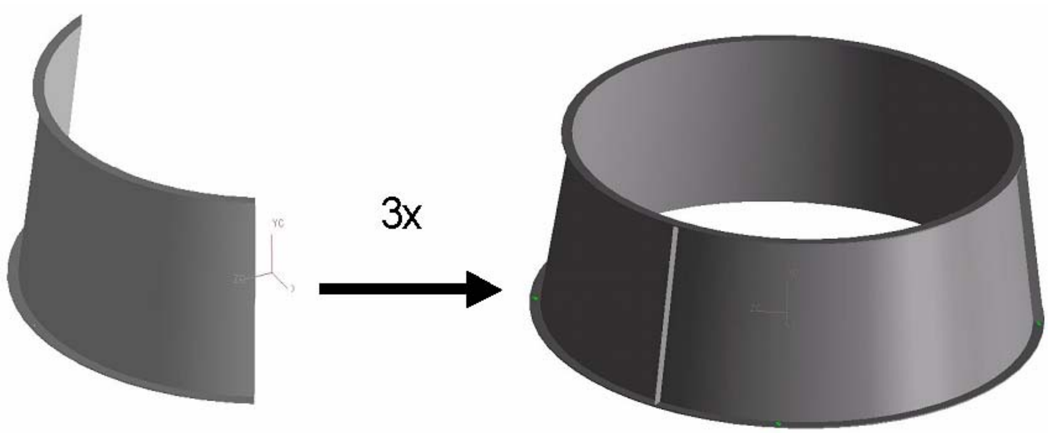


Figure 3.3.1.2.7-4 RICH Reflector Construction

The lower layer of the RICH construction contains the primary structure that supports the RICH and interfaces to the Lower USS-02. Within the secondary structure of the lower assembly are the rectangular and triangular arrays of photomultiplier tubes that will detect the photons from the Cerenkov radiation. Construction of the Lower RICH support structure and PMT support grids are shown in Figure 3.3.1.2.7-5.

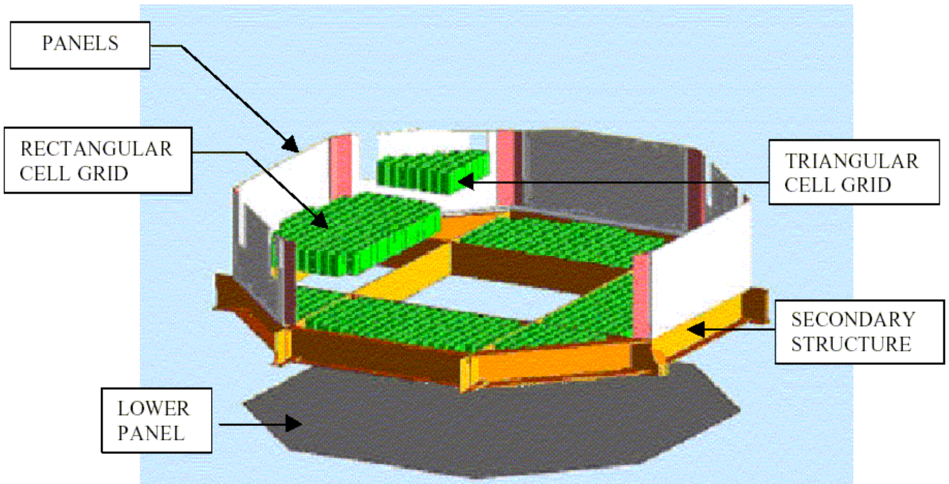


Figure 3.3.1.2.7-5 Lower RICH Construction

The PMTs for the RICH are constructed using Hamamatsu R7600 M16 photomultiplier tubes and a 4x4 matrix of light guides to correlate with the 4x4 photocathode grid of the photomultiplier tube. An optical pad assures the proper transmission of light into the photomultiplier tube and also seals off the glass front of the vacuum tube. The light guides are compressed into this optical pad using Nylon cords to assure good light transmissivity. The assembly of an individual PMT is shown in Figure 3.3.1.2.7-6.

The base of the photomultiplier tube is potted and the boards of the PMT are conformally coated to protect the electronics and to limit the coronal breakdown potential for the high voltage system. The welded soft iron outer body provides attenuation of the magnetic fields and support interfaces for integrating into the triangular and rectangular grids that form the arrays that cover the octagonal configuration.

The RICH PMTs are powered by four RICH high voltage bricks attached to the Lower USS-02 structure. Each of these bricks generates voltages at 1000 VDC and supplies this voltage to the PMTs. The RICH high voltage bricks are fully potted as are the high voltage electronics on the PMTs. The cabling used to route this power is rated in excess of the voltages present and use high voltage connection techniques to eliminate possible sources for discharge, corona and electrical shock. The signals from the PMTs are sent to the R Crate for data processing to establish the high energy particle or radiation incident characteristics.

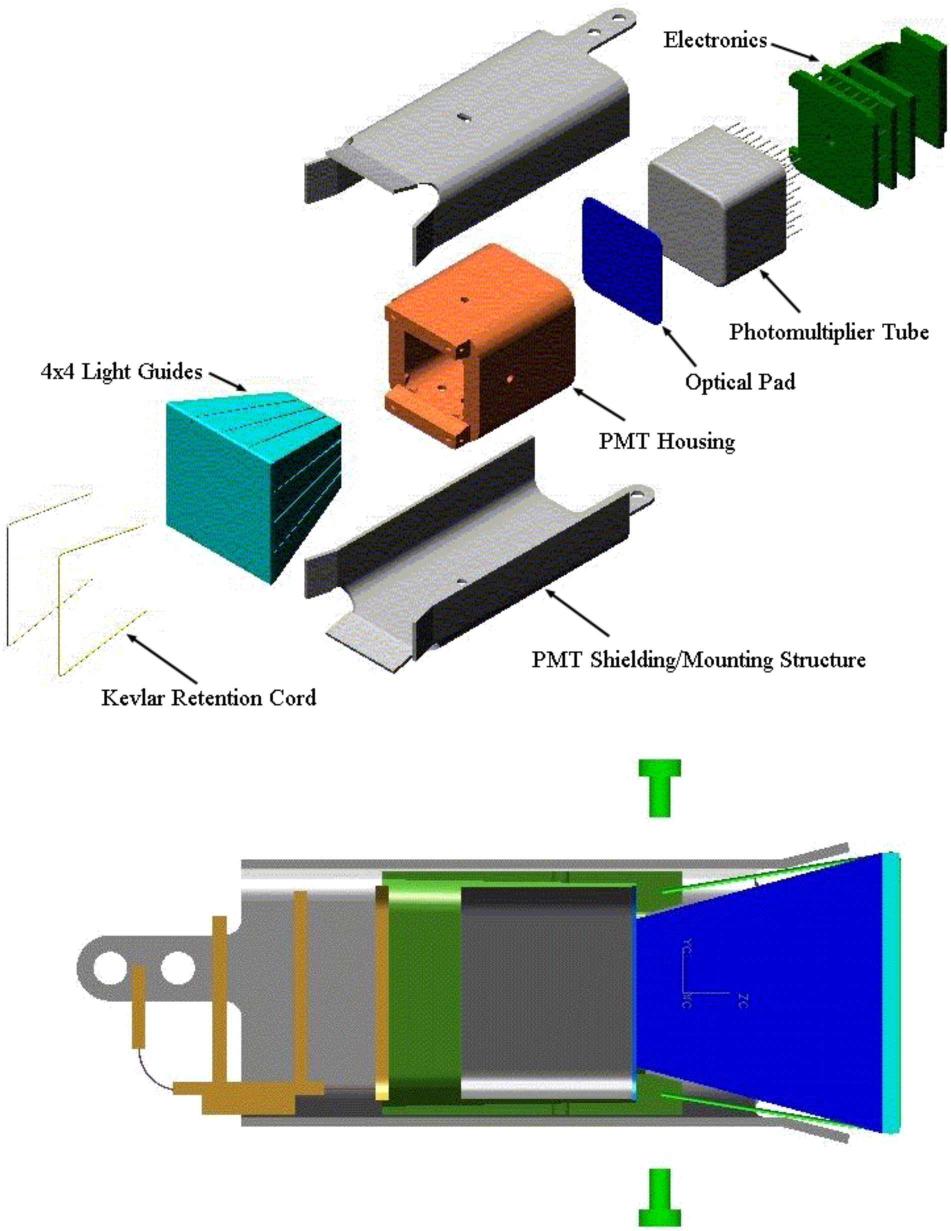


Figure 3.3.1.2.7-6 – RICH PMT Construction (Kevlar cord replaced with Nylon wire)

The 406 lb (184 kg) RICH interfaces with 8 flanges on the Lower USS-02 as shown in Figure 3.3.1.2.7-7. Each interfaces uses 2 bolts per flange (16 total) secure the RICH to the Lower USS-02. Each of these flanges is riveted to the Lower USS-02 box beams with 24 structural rivets.

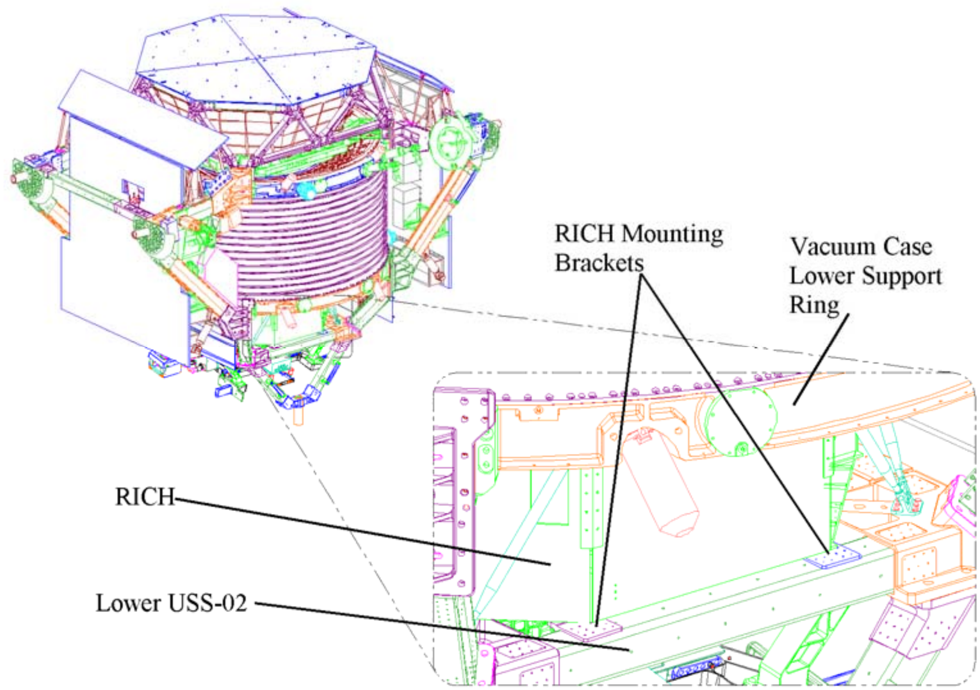


Figure 3.3.1.2.7-7 – RICH Structural Interface

3.3.1.2.8 Electromagnetic Calorimeter (ECAL)

The Electromagnetic Calorimeter (ECAL) of the AMS-02 experiment is a fine grained lead-scintillating fiber sampling calorimeter that allows precise, 3-dimensional imaging of the shower of particles generates by an incoming event. This allows electrons to be distinguished very easily from hadrons and provides good energy resolution. The calorimeter also provides a stand-alone photon trigger capability to AMS. The ECAL measures the energy of electrons, positrons and gamma rays up to 1 TeV.

The active sensing element of the ECAL consists of layers of lead foils and polymer scintillating fibers (Figure 3.3.1.2.8-1). Each foil is a lead-antimony alloy with a density of 11.2 ± 0.5 gr/cm^{3}with an effective thickness of 0.04 inch (1 mm). Each lead layer is grooved on both sides (Figure 3.3.1.2.8-2) to accommodate PolyHiTech Polifi 0244-100 scintillating fibers. Each fiber is 1.0 mm in diameter and is secured in the aligned groves with BICRON BC-600 Optical glue applied as lead layers are assembled and pressed together. Each layer consists of 490 fibers across the 25.9 inch (658 mm) width. Lead layers are grouped together in "superlayers" comprised of eleven layers of lead foil and ten layers of scintillating fibers. Each superlayer has all scintillating fibers oriented in the same direction, alternating the direction orthogonally of the fibers with each of the superlayers. Once assembled and pressed, each cured superlayer is milled to a uniform thickness of 0.7 inch (18.5 mm) thick. The superlayers are then assembled and milled into squares with 25.9-inch (658 mm) sides. The last (bottom) lead layer of the bottom superlayer has been replaced with a milled aluminum plate to reduce weight of the overall ECAL. Estimated savings by replacing the last plate with aluminum is approximately 2 kg.

Figure 3.3.1.2.8-1 Three Superlayers Showing Alternating Layers Of Lead Foil And Scintillating Fibers And Alternating Superlayer Orientation

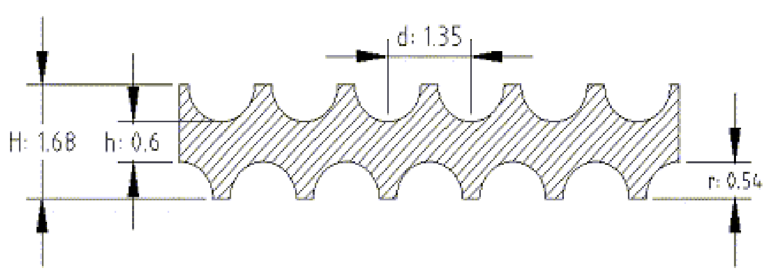


Figure 3.3.1.2.8-2 Individual Lead Foil Profile (Dimensions in mm)

The “pancake” of lead layers with scintillating fibers is the foundation of the ECAL sensor. Sensitive photomultiplier tubes (PMTs) are positioned around the periphery of the brick to sense photons generated by the passage of particles, secured against the edges of the brick where the Super-layer fibers terminate.

The ECAL is approximately 31.5 inches (800 mm) square x 9.8 inches (250 mm) high and weighs approximately 1478 lbs (643 Kg). Approximately 75% of this weight is due to the lead foils.

The ECAL “pancake” is supported by the ECAL “box”. The box is made of 6 elements (Figure 3.3.1.2.8-3). The top and bottom pieces are aluminum honeycomb plates framed with aluminum. The plates are bolted to four lateral panels along the edges. The four lateral panels are made of Aluminum plates, 4 inch (10.16 cm) thick, carved with squared holes of 1.26-inch (32 mm) sides to house the light collection system. Four corner brackets, made of Aluminum plate, link the four plates together and connect the detector to the USS-02 at the bottom of the AMS-02 instrument (Figure 3.3.1.2.8-4). The four mounting locations include a pair of radially slotted holes so that the loads of the ECAL are transferred to the USS-02, but the loads from the USS-02 that are transferred into the ECAL are limited.

The light collection system is mounted about the periphery of the ECAL pancake in the four lateral panels. Two sides, serving four super-layers, have 72 holes while the two other faces, serving 5 super-layers, have 90 holes each.

The ECAL Intermediate Boards (EIBs) are electronic boards coated and fixed in aluminum frames directly mounted on the ECAL back panels. The EIBs provide the interface for the PMTs to get commands from the data acquisition system and to send data from driver electronics to it.

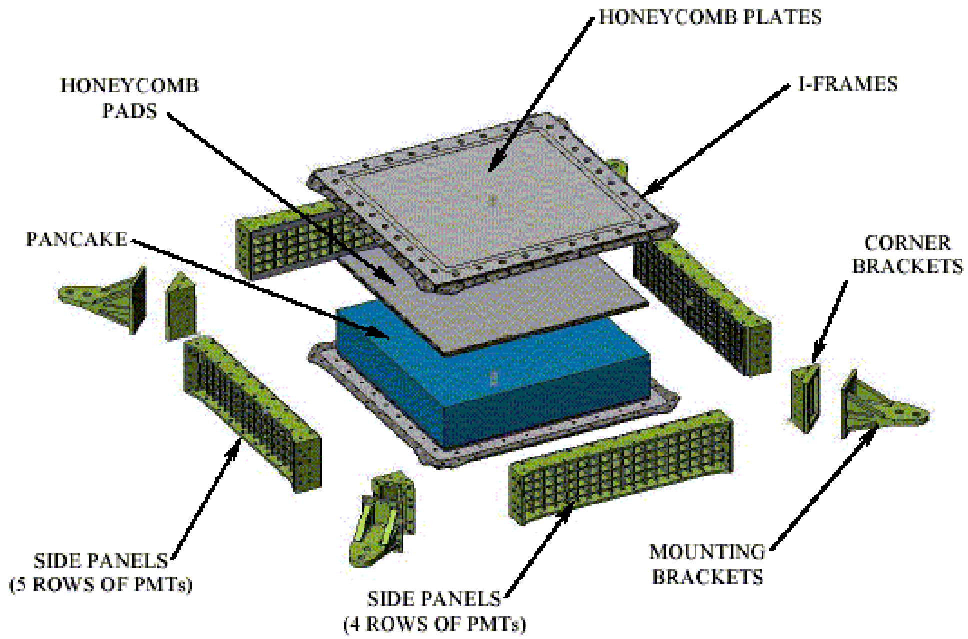


Figure 3.3.1.2.8-3 ECAL Construction

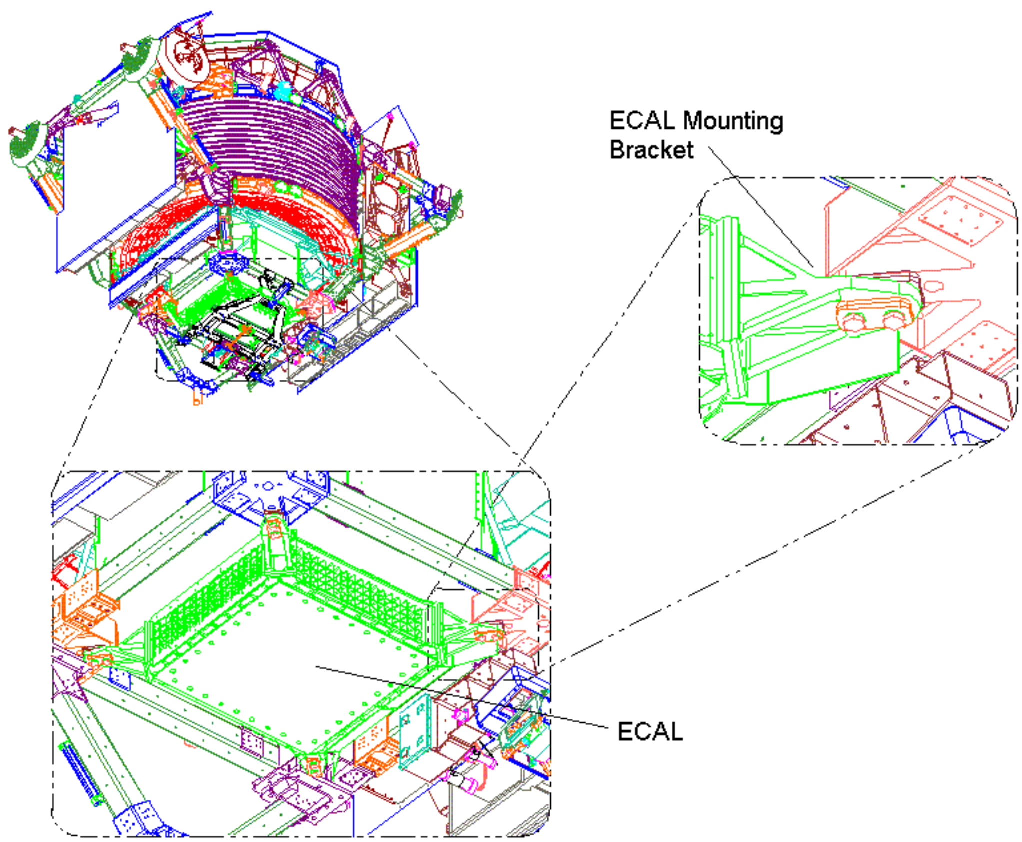


Figure 3.3.1.2.8-4 Location of the ECAL on the AMS-02

The ECAL utilizes two types of electronics boxes, the E-Crate and ECAL High Voltage (EHV) boxes, which are mounted to the lower USS-02 structure (Figure 3.3.1.2.8-5). The two E-Crates provide data acquisition and triggering functions and the four EHV boxes contain high voltage (HV) bricks – each with 55 HV channels per brick – supply the high voltages for PMT operations. The HV bricks are fully potted. Two EHV boxes mounted on diagonally opposite legs of the lower USS-02 accommodate two HV bricks each, while the EHV boxes mounted on the two other legs accommodate one brick each. Three bricks are packaged per each of the four EHV boxes. The ECAL utilizes high voltages up to 800 VDC to operate the PMTs.

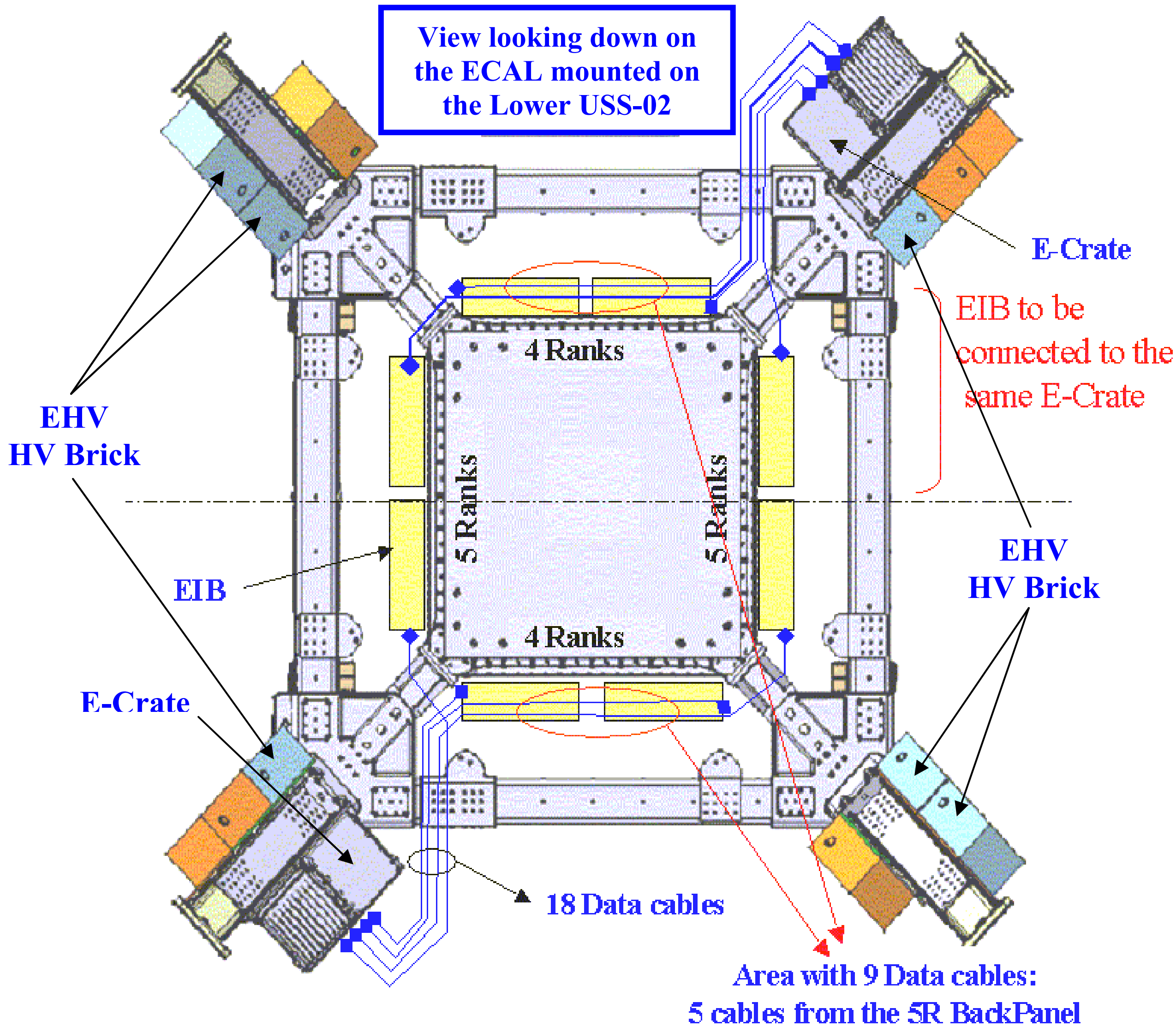


Figure 3.3.1.2.8-5 – Location of E-Crates And EHV High Voltage Bricks

3.3.1.2.9 Star Tracker

The Space Station, which is large and fairly flexible, cannot measure its own position with a high degree of accuracy and thus cannot directly tell the AMS-02 where it is exactly and where it is pointing. To optimize science from the Tracker detector carried by AMS it is important to have the capability to determine accurately the position of the AMS payload at the exact time that an event occurs. To accurately determine its position, AMS carries a Star Tracker called AMICA (for Astro Mapper for Instrument Check of Attitude). AMICA is equipped with a pair of small optical telescopes (AMICA Star Tracker Cameras or ASTCs). The ASTCs are mounted to the upper Vacuum Case Conical Flange on opposite sides of AMS to increase the probability that one has a clear view of the stars (Figure 3.3.1.2.9-1).

Each camera acquires an image of the stars with a Charged Coupling Device (CCD) detector (Figure 3.3.1.2.9-2) and compares the resultant image to an on-board sky map. With this information, the attitude of AMS can be determined within a few arc-seconds (arc-sec) accuracy.

The hardware consists of an optics system (Figure 3.3.1.2.9-4) [f/1.25 lens with 75 mm focal length and a 6.3° X 6.3° field of view (FoV)]; a lens cover containing a 3 mm thick blue filter and a 2 mm thick red filter; a low noise frame-transfer CCD (512 X 512 pixels); and a baffle to limit the stray light intrusion to the optics. The baffle is made of black anodized aluminum Al 6061 that is 1 mm thick. The baffle is not mechanically connected to the lens assembly and is supported independently by a bracket mounting the baffle to the M-Structure (Figure 3.3.1.2.9-3), the configuration allowing for relative motion between the baffle and the lenses without leaking light into the optical path. The interface between the baffle and the lens assembly is made light tight by a fabric MLI cover.

The AMICA operates on 28 Vdc. The ASTCs are interfaced to the M-crate located on the ram side by three cables, two 8 conductor 24 AWG shielded conductors to provide the SpaceWire Link for data and one three conductor 22 AWG cable for power. The thermal load from the Star Tracker CCD and electronics board inside the sensors is carried by a copper "bus" to the thermal blocks connecting to the Tracker Thermal Control System. The CCD and power switching boards for each ASTC are contained in the AMICA Star Tracker Supports (ASTSs) that attach the instrument to the Tracker.

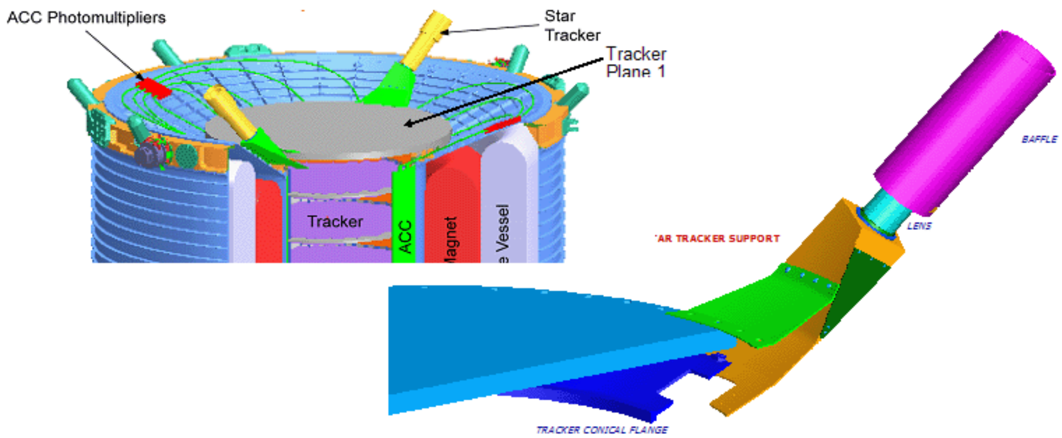


Figure 3.3.1.2.9-1 – Star Tracker Mounting Location

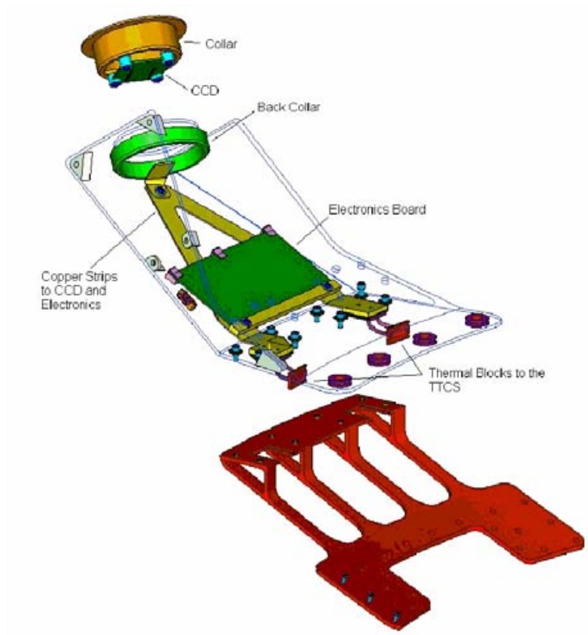


Figure 3.3.1.2.9-2 – Star Tracker CCD and Electronics

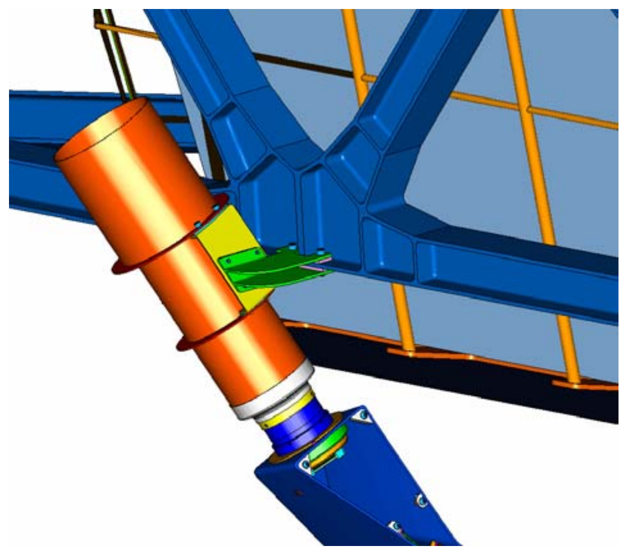


Figure 3.3.1.2.9-3 – Star Tracker Baffle Mounting

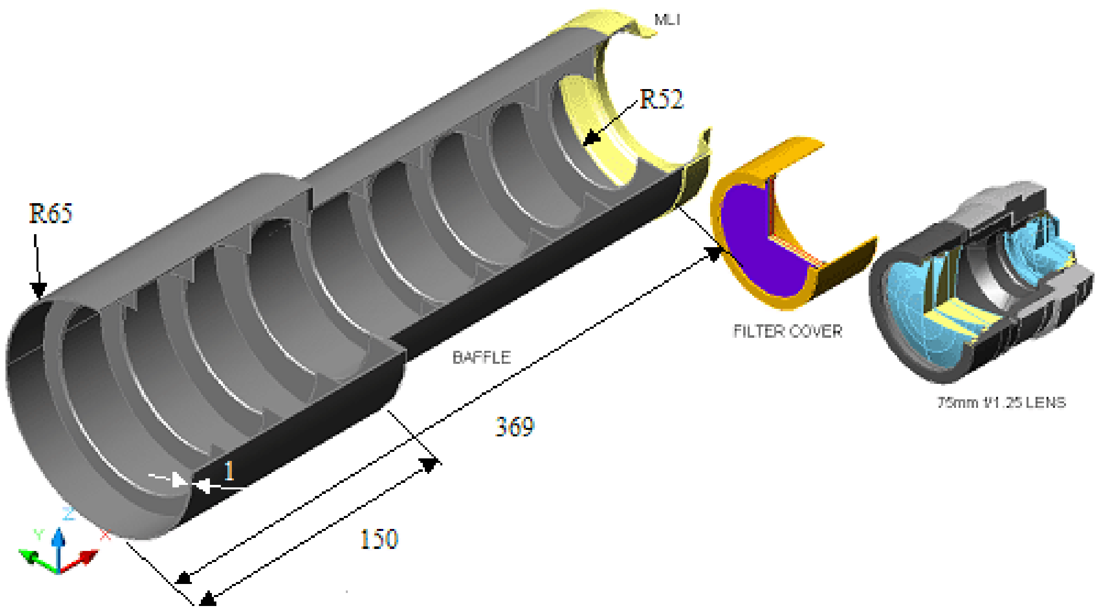


Figure 3.3.1.2.9-4 Baffle and Optics Design

3.3.1.2.10 Global Positioning System (GPS)

The AMS-02 utilizes an ALCATEL TOPSTAR 3000D which will be integrated into AMS by IN2P3-Montpellier. A single patch type antenna (Sextant Avionique model 3407-79) will be mounted on an upper USS-02 structural member. A signal from the GPS unit will be used for precision time correlation that exceeds the capabilities of the ISS to provide. The need for the GPS is to correct time drift over time within the precision timing systems that trigger the particle events.

Interface electronics within the M-Crate receive the precise time at which the timing pulse from the GPS unit was emitted and this is included, along with the value of the local timer, in the event data. To reach the required accuracy, software has been developed to include all the corrections required for low earth orbit GPS applications. The GPS operates off of the AMS-02 internal 28 VDC power bus.

3.3.1.2.11 Data and Interface Electronics

The AMS avionics primary functions are front end data collection for the scientific instruments, data and command communication interface between the various portions of the payload, as well as between the payload and the STS and ISS; and power distribution throughout the payload.

AMS-02 contains numerous electronics boxes, some termed “Crates,” that supply the necessary readout/monitor/control electronics and power distribution for each detector (Figures 3.3.1.2.11-

1 and 3.3.1.2.11-2). The box nomenclature is generically x-Crate or xPD, where "x" is a letter designating the detector function, and "Crate" refers to the readout/monitor/control electronics box and "PD" refers to the Power Distribution box for that specific detector. Similarly xHV bricks provide high voltage for some detectors. Values of "x" are designated as follows:

- E ECAL
- J Main Data Computers (MDC) and Command & Data Handling interfaces
- JT Trigger and central data acquisition
- M Monitoring
- R RICH
- S Time of Flight (TOF) Counters and Anti-Coincidence Counters (ACC)
- T Tracker
- TT Tracker Thermal
- U Transition Radiation Detector (TRD)
- UG TRD Gas

Additionally, electronics are mounted in the Power Distribution System (PDS), the Cryomagnetic Avionics Box (CAB), the Cryocooler Electronics Box (CCEB), and the Uninterruptible Power Supply (UPS).

The interface boxes PDS and J-Crate provide the isolation and protection functions necessary to protect the STS and ISS vehicles from damage. In most cases the PDS provides the isolation and circuit protection required to prevent feedback to the ISS; however, the Cryomagnet Avionics Box (CAB); the Cryocooler Electronics Box (CCEB); and some Heater Circuits receive 120Vdc pass-through power from the PDS.

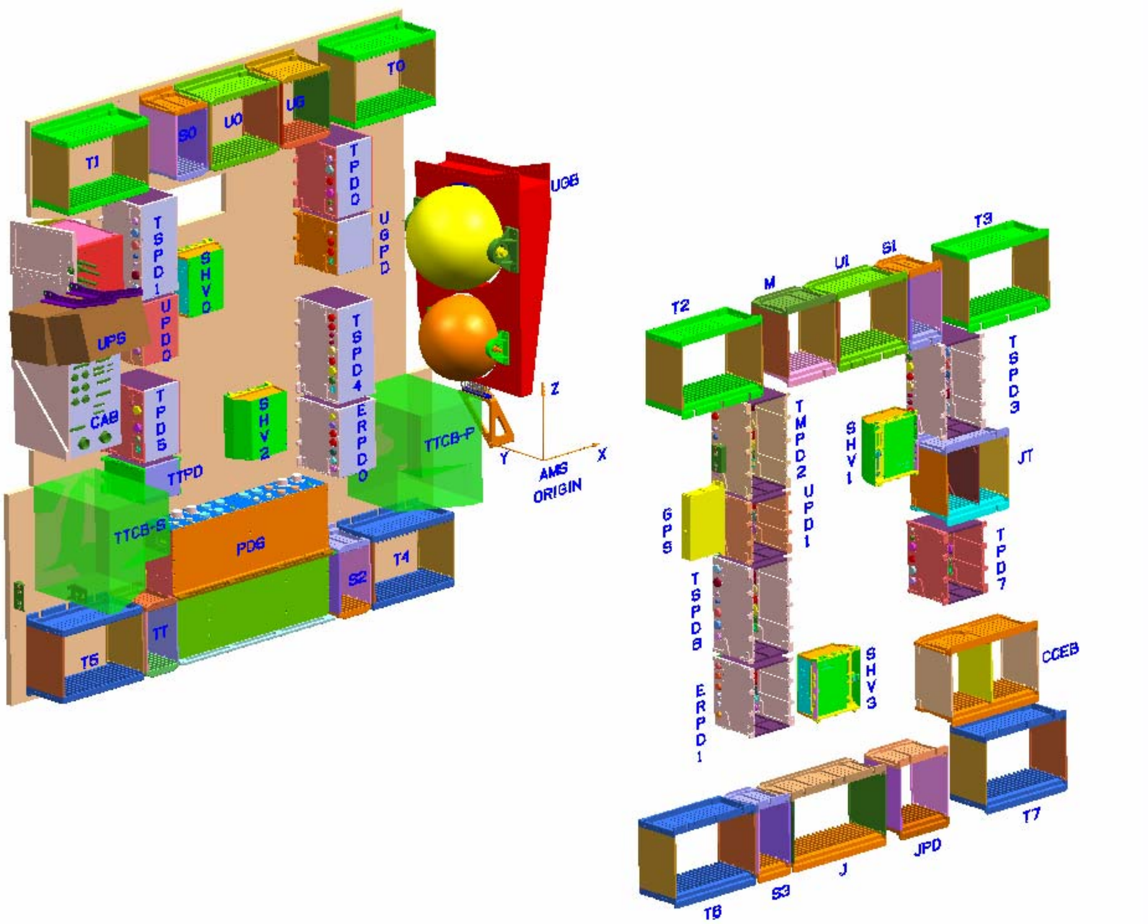


Figure 3.3.1.2.11-1 Electronics Crate Locations

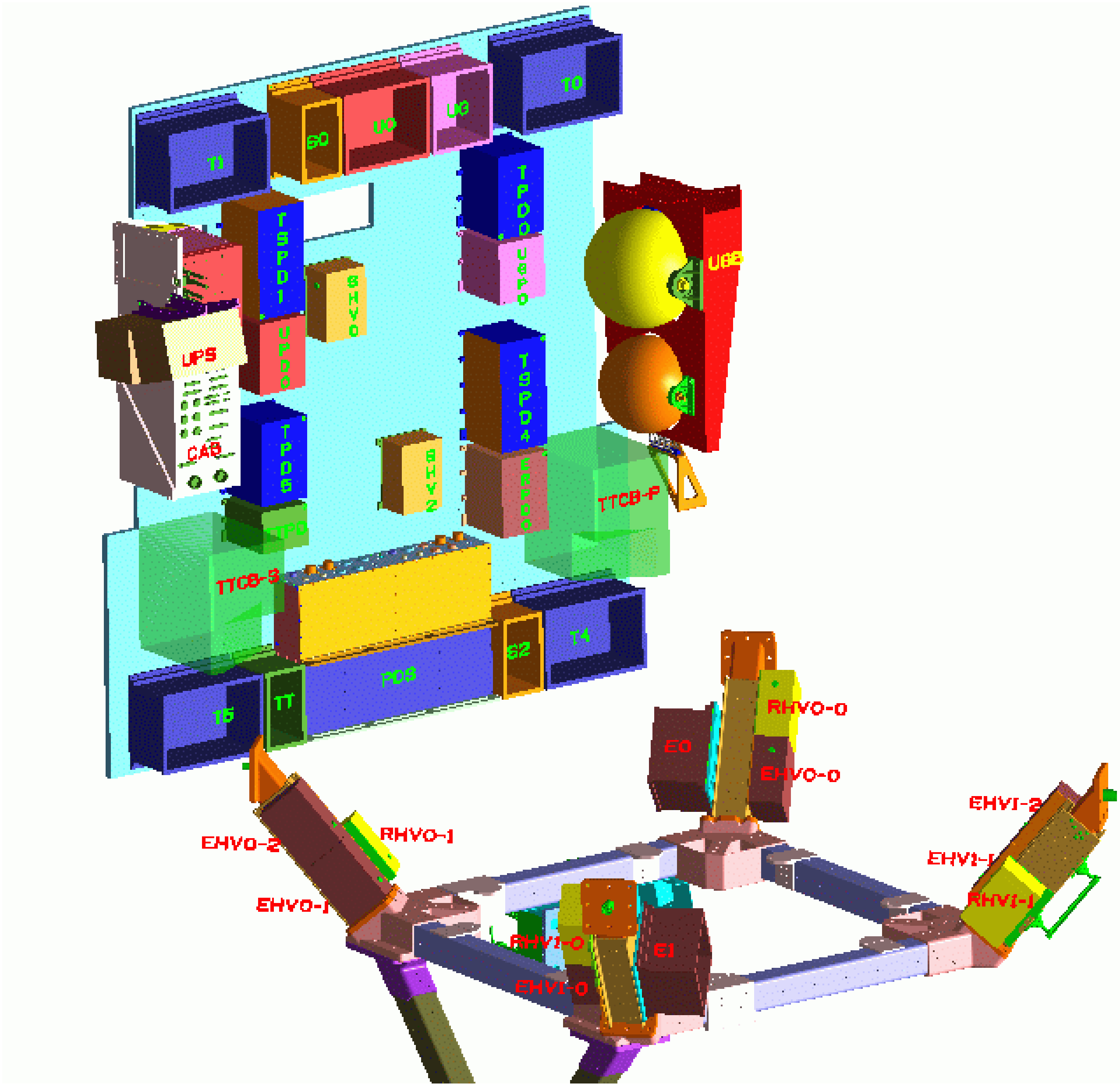


Figure 3.3.1.2.11-2 Electronics Crate Locations

3.3.1.2.11.1 Power Distribution System (PDS)

The AMS-02 Power Distribution System (PDS) serves as the primary front-end for the power distribution to the subsystems and experiment detector electronics. It performs power conversion and distribution functions described in Section 5.12.3. The power isolation within the PDS is designed to meet the 1 Mega Ohm Isolation requirement defined in SSP-57003.

Wire sizing has been selected in compliance with the requirements defined in NSTS 1700.7b, "Safety Policy and Requirements for Payloads Using the Space Transportation System", NSTS 1700.7b ISS Addendum, "Safety Policy and Requirements for Payloads Using the International Space Station", and NASA Technical Memorandum TM 102179, "Selection of Wires and Circuit Protection Devices for NSTS Orbiter Vehicle Payload Electrical Circuits".

Power for the AMS-02 Payload is supplied from several sources dependent upon mission phase. During pre-launch operations the power is supplied through the Orbiter T-0 connection through the Orbiter ROEU to the AMS-02 and the AMS-02 PDS. During Orbiter Operations APCU 120 VDC and Orbiter 28VDC are supplied through the ROEU to the AMS-02 through the AMS-02 PDS. During Space Station RMS operations power (120VDC) is supplied to the AMS-02 through the PVGF to the PDS to power heaters on the AMS-02. Once attached to the ISS truss the ISS Supplied 120 VDC is routed through the UMA through the AMS-02 PDS to the AMS-02 Systems. See Table 3.3.1.2.11.1-1 for details on PDS interface details.

The PDS, the yellow shaded box in Figure 3.3.1.2.11.1-3a & -3b, consists of four distinct sections: 120 Vdc Input; 120 Vdc Output; 28 Vdc Output; and Low Voltage Control and Monitor. The bus to bus isolation of the 120Vdc outputs is provided by the end-subsystem, by either DC-to-DC or AC converters, or relays. The isolation for all other outputs is provided internally to the PDS by DC-to-DC converters. The PDS has two independent "channels" side A and side B which have four identical subsections. The only difference between the two channels is that side A is the only side that provides power to the CAB for magnet charging.

The PDS is located on the Main Wake Crate Rack very close to the Passive Umbilical Mechanism Assembly.

Figure 3.3.1.2.11.1-1a Payload Power Interfaces

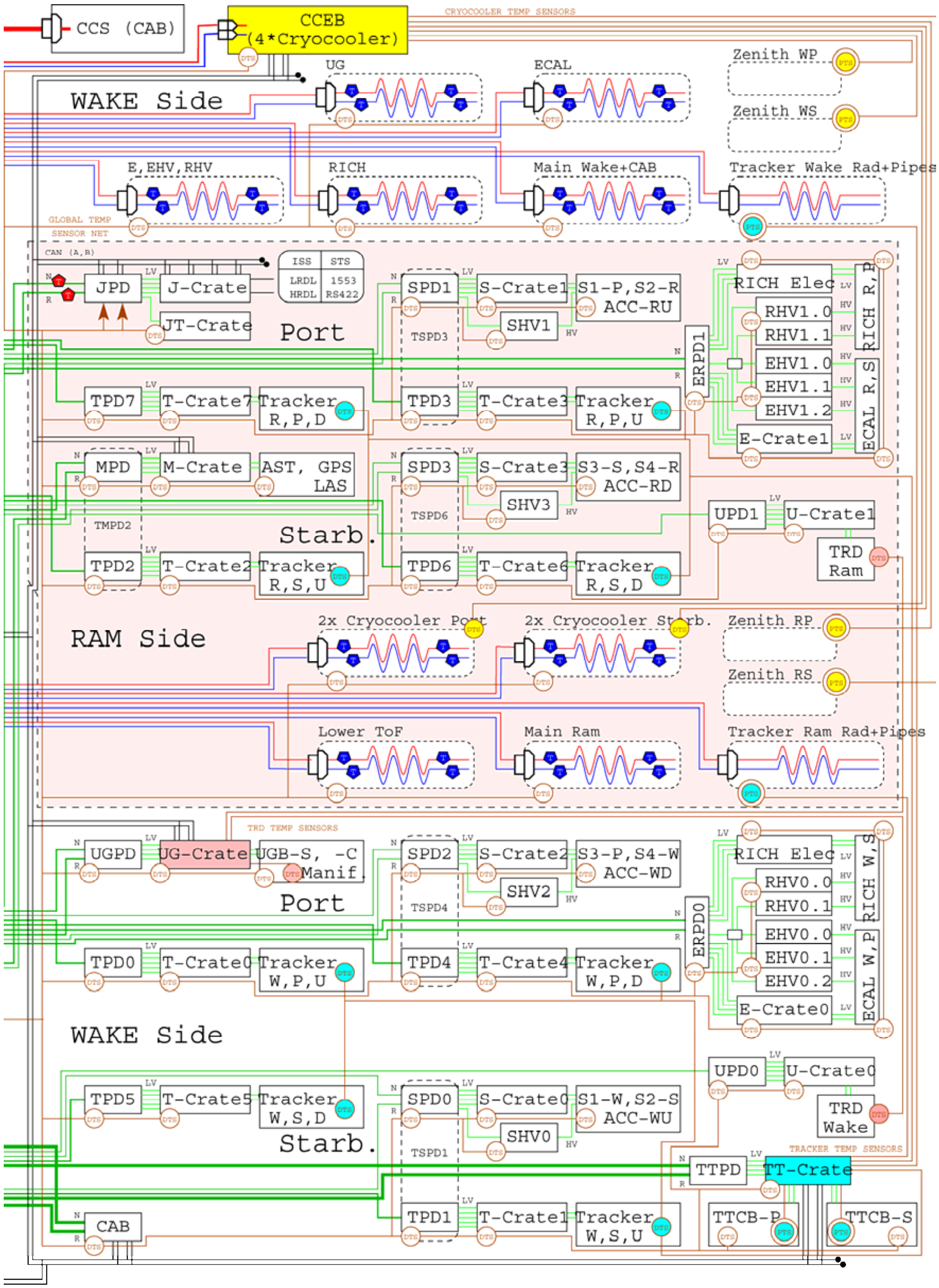


Figure 3.3.1.2.11.1-1b Payload Power Interfaces

TABLE 3.3.1.2.11.1-1 PDS SECTION INTERFACE DETAILS

PDS SIGNAL & POWER INTERFACES		
INPUT SECTION		
ISS	Power I/F input	• 120V Feeder A • 120V Feeder B
STS	Power I/F input	• 120V Feeder APCU • 120V Feeder T0
BCS (PVGF)	Power I/F input	• 120V Feeder PVGF 1 • 120V Feeder PVGF 2
EMI FILTER		• EMI I/F
INPUT TELEMETRY		
INPUT TELEMETRY	Signal I/F	(Via internal serial I/F to the CAN BUS module) • INPUT CURRENT • INPUT VOLTAGE
INTERNAL POWER SUPPLY SECTION		
ESEM 1-A	Power I/F	15V Internal Power Supply

	Signal I/F	(Via internal serial I/F to the CAN BUS module)
		• ON/OFF DC/DC CONVERTER
		• DIGITAL Board Status Monitoring
		  • OK/NOK
		  • OVERTEMP
		  • DC/DC 1 OVERCURRENT
		  • DC/DC 2 OVERCURRENT
		  • DC/DC 1 MAIN ON/OFF
		  • DC/DC 2 MAIN ON/OFF
		  • MAIN POWER ON
		  • DIGITAL TEST OUT
		• ANALOGUE Board Monitoring
		  • TEMPERATURE
		  • ANALOG REFERENCE VOLTAGE
		  • MAIN POWER VOLTAGE

120V OUTPUT SECTION		
DIRECT OUTPUT	Power I/F	• 120V Feeder to CCS in CAB
ESEM 3-B	Power I/F	• OUT 1 for AMS heaters • OUT 2 for AMS heaters • OUT 3 for AMS heaters • OUT 4 for AMS heaters • OUT 5 for AMS heaters • OUT 6 for AMS heaters • OUT 7 for AMS heaters • OUT 8 for AMS heaters • OUT 9 for AMS heaters • OUT 10 for AMS heaters • OUT 11 for AMS heaters • OUT 12 CCEB (Cryocoolers)

TABLE 3.3.1.2.11.1-1 PDS SECTION INTERFACE DETAILS (CONTINUED)

PDS SIGNAL & POWER INTERFACES		

	Signal I/F	(Via internal serial I/F to the CAN BUS module)
		• ON/OFF OUTLET Command
		• DIGITAL Board Status Monitoring
		  • OK/NOK
		  • OVERTEMP
		  • OUTLET STATUS (ON/OFF)
		  • OUTLET TRIP STATUS (only for CCEB line)
		• ANALOGUE Board Monitoring
		  • TEMPERATURE
		  • OUTLET CURRENT (only for the CCEB line)
		  • ANALOG REFERENCE VOLTAGE

120V TO 28V CONVERSION SECTION		
PB2	Power I/F	• 28V OUTPUT to the ESEM 3-A distribution board

PB2	Signal I/F	(Via internal serial I/F to the CAN BUS module)
		• ON/OFF DC/DC CONVERTER Command
		• DIGITAL Board Status Monitoring
		  • OK/NOK
		  • OVERTEMP
		  • DC/DC CONVERTER STATUS (ON/OFF)
		  • INPUT OVERCURRENT
		  • OUTPUT OVERVOLTAGE
		• ANALOGUE Board Monitoring
		  • TEMPERATURE
		  • 28V OUTPUT VOLTAGE
		  • ANALOG REFERENCE VOLTAGE

ESEM 3-A	Power I/F	• 8 x 28V output lines
		  • out 1 to 7 @ 5A each
		  • out 8 @ 10A

ESEM 3-A	Signal I/F	(Via internal serial I/F to the CAN BUS module)
		• ON/OFF OUTLET Command
		• DIGITAL Board Status Monitoring
		  • OK/NOK
		  • OVERTEMP
		  • OUTLET STATUS (ON/OFF)
		  • OUTLET TRIP STATUS
		• ANALOGUE Board Monitoring
		  • TEMPERATURE
		  • OUTLETS CURRENT
		  • ANALOG REFERENCE VOLTAGE

DIGITAL I/F SECTION		
CAN BUS I/F	Signal I/F	• CAN BUS I/F • PDS INTERNAL BUS I/F • DIGITAL Command to the boards • ANALOGUE ACQUISITIONS of the boards telemetry • DIGITAL ACQUISITIONS of the boards status

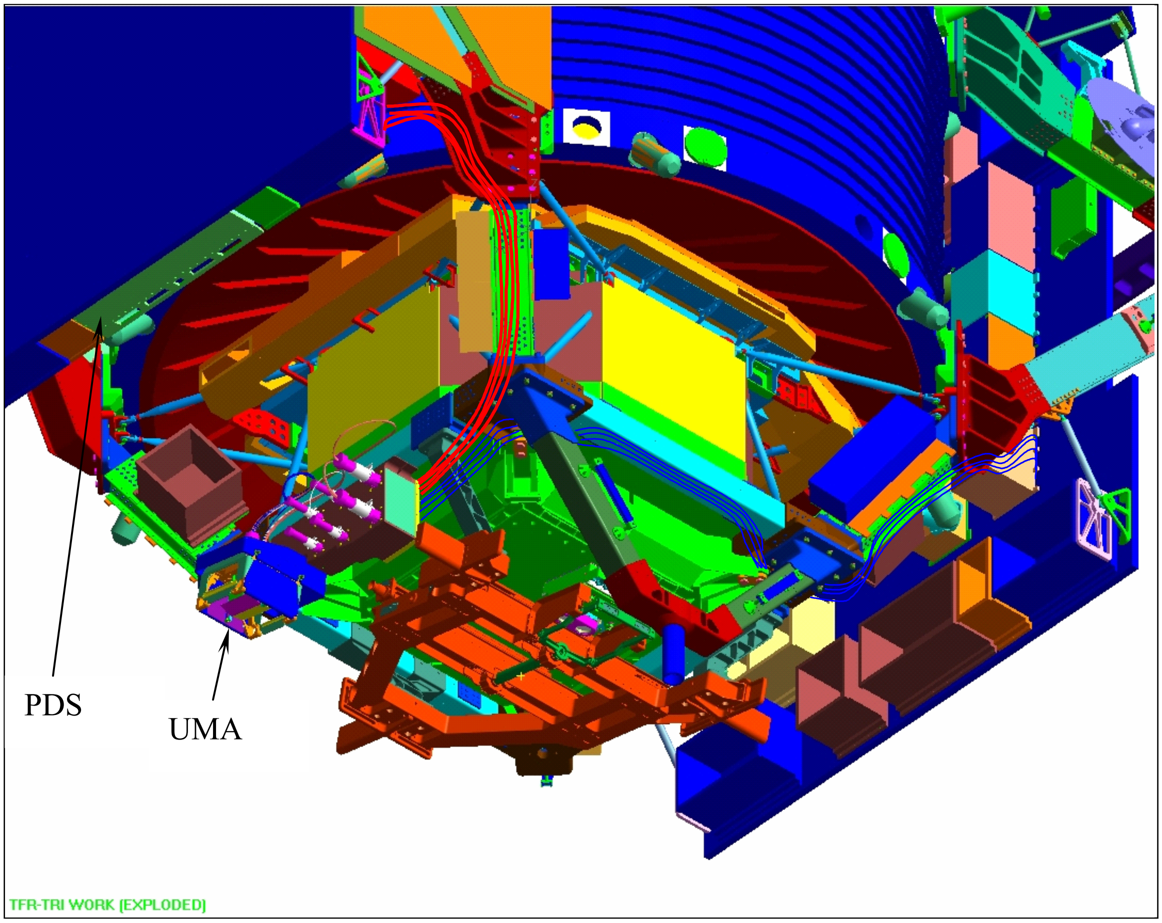


Figure 3.3.1.2.11.1-2 Location of the PDS and UMA on AMS-02

3.3.1.2.11.2 Cryomagnet Avionics Box (CAB)

The CAB is designed to perform all control and monitoring functions for the Cryomagnet Subsystem (including SFHe Tank and Vacuum Case). The CAB consists of four sections: the Cryomagnet Current Source (CCS); the Cryo Controller and Signal Conditioner (CCSC); the Cryomagnet Self Protection (CSP); and the Power Switches (PS) (Figure 3.3.1.2.11.2-1).

The CAB is located on the Unique Support Structure (USS) very close to the current input port of the Vacuum Case to minimize the length of the Cryomagnet Current Leads.

High Voltage Isolation is provided at all inputs to the CAB from the ISS side to prevent passing any high-voltage that could be developed during a multiple fault "unassisted" quench back to the ISS power or data systems. Isolation for the 120Vdc line (feed thru from PDS) is performed via DC-to-DC Converters in the CCS. Analysis has shown that the maximum voltage that could be achieved during an "unassisted" quench is 5.5kV. 8kV isolation is provided at all these points to ensure margin. The unassisted quench is an off-nominal scenario, and would result in damage to the CAB and the magnet that would render them unusable, but not create a safety hazard. The one fault "assisted" quench would prevent these voltage levels from arising and protect the CAB and the magnet for mission success.

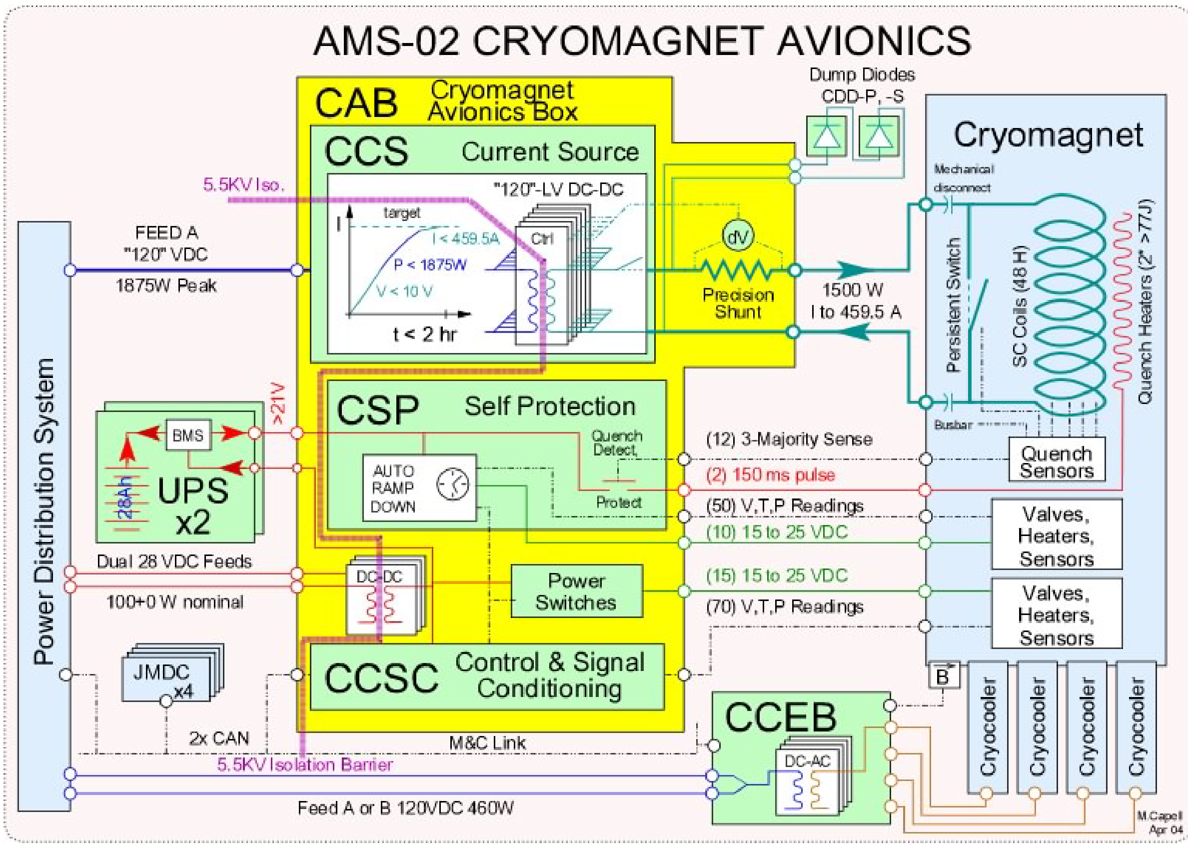


Figure 3.3.1.2.11.2-1 Schematic of the AMS-02 Cryomagnet Avionics Box (CAB) and Cryomagnet

3.3.1.2.11.3 Cryomagnet Current Source (CCS)

The 120 Vdc Power input (feed through from the PDS) is routed solely to the CCS. A DC-to-DC converter at the input to the CCS provides isolation for this Power Bus. The 120 Vdc power is required only for magnet charging. All other sections of the CAB are operated with 28 Vdc from the PDS.

The 120 Vdc input is limited to a maximum of 1875 W for power management. Power supplied to the DC-to-DC converter is controlled by Opto-Isolating feedback from the DC-to-DC converter output with a power switch and pulse width modulation of the input.

To charge the magnet, the Semiconductor switch on the charging circuit is closed, and power is supplied to the transformer input. The current is slowly ramped up over a period of approximately 1.5 hours to 459 Amps. Current during charge and discharge operations is monitored using a 500A shunt. The connection from the CCS to the magnet is made via three pairs of AWG 2/0 wires. Once full operating current is reached, the Persistent Switch is closed (the switch consists of a pair of super-conducting wires – "closed" by cooling them down to superconducting temperatures). With the persistent switch closed, 459 A is running through both sides of the circuit (the magnet side and the charger side). To avoid ripple currents through the persistent switch, the current on the charger side is slowly reduced to zero. Once the current on the charger side is depleted, the Semiconductor Switch is opened, and the Charging System is disconnected from the Magnet Circuit.

If an event occurs that necessitates a power down of the magnet, the system is designed to perform a nominal "ramp down" function. The nominal ramp down is the most acceptable method for powering down the magnet without the potential for substantially decreasing the endurance of the magnet. To perform a ramp down, the mechanical leads are connected and the persistent switch is opened (by allowing it to warm to a non-superconducting state), diverting the current from the magnet through the Cryomagnet Dump Diodes (CDDs). The connection from the magnet is to the CAB with three pairs of AWG 2/0 wires, and then on to the CDD, with a loop of one AWG 2/0 wire. The energy from the magnet is dissipated in the form of heat through the CDD chain. The CDD consists of six sets in series of three diodes in parallel that are used solely for the purpose of dissipating the stored energy of the magnet. These dump diodes are located on the two wake-side sill trunnion joints (three sets on each joint), which were selected for their large thermal mass. The CDDs are protected by a metal cover to prevent incidental contact by ground personnel or crew. The total time required to dissipate the magnet energy is estimated to be 80 minutes.

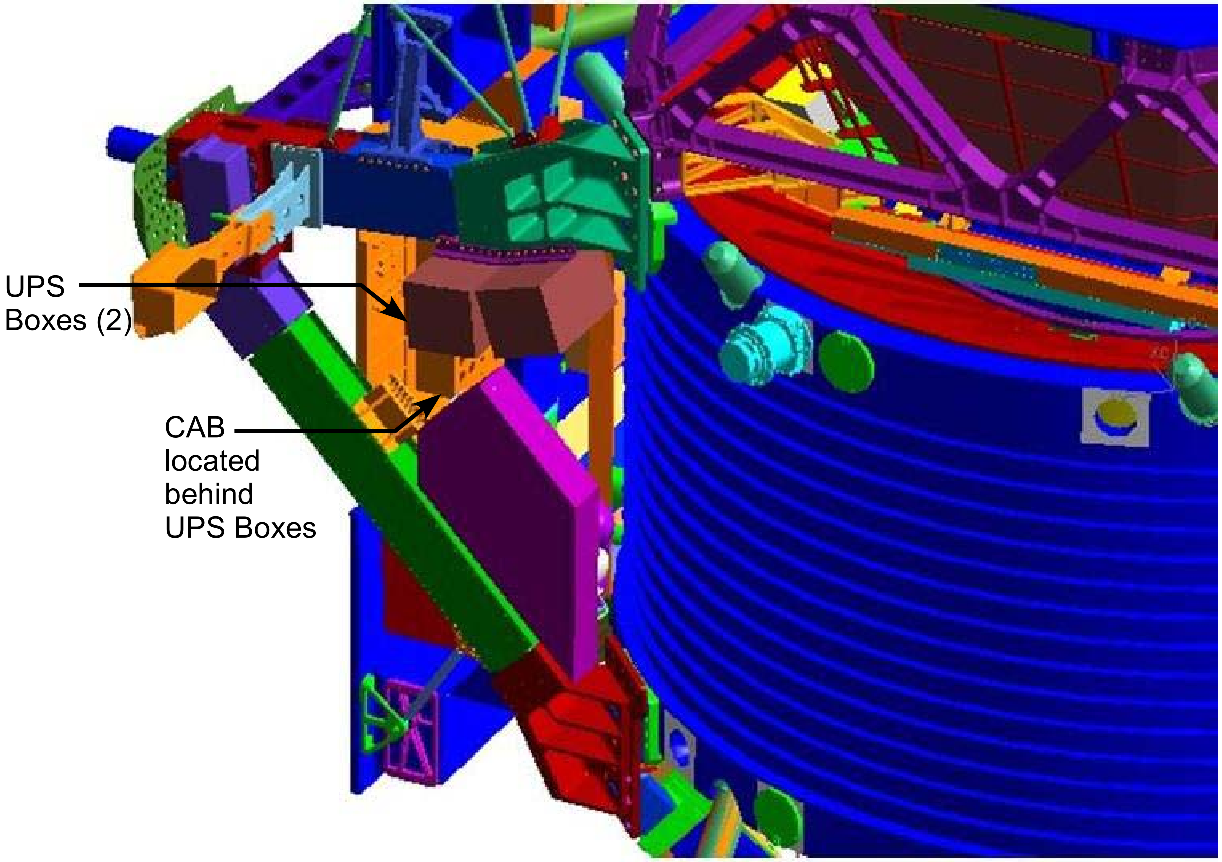


Figure 3.3.1.2.11.3-2 Cryomagnet Avionics Box (CAB) on the USS-02

3.3.1.2.11.4 Cryomagnet Control and Signal Conditioning (CCSC)

The CCSC provides the interface between the AMS-02 Main Data Computers (MDCs) and the Cryomagnet. The CCSC is responsible for:

- reception of commands from the MDCs
- transmission of telemetry to the MDCs
- commanding of the CCS
- control of the Cryomagnet auxiliary functions (i.e. heaters, valves, etc.)
- monitoring of the CCS, Cryomagnet, and CAB operating parameters and status

The CCSC also performs system fault detection and management functions, formatting of telemetry, and data storage for system status. The CCSC is required to interface with the Uninterruptible Power Source (UPS).

3.3.1.2.11.5 Power Switches

The power switches control the 28 VDC power supply to valves and cryogenic heaters. With the exception of the power switches controlled directly by the CSP, the power switches are galvanically isolated from the 28 VDC power bus.

3.3.1.2.11.6 Cryomagnet Self Protection (CSP)

Super-conducting magnets, such as the one utilized by AMS-02, may develop a condition where a portion of the coil begins to rise above super-conducting temperatures. When this condition occurs, the section of wire affected begins to develop resistance, and the current running through this resistance begins to heat the wire rapidly. This eventually leads to dissipation of the magnet energy (in the form of heat) within the magnet, and is referred to as a magnet quench. This condition is highly undesirable from a mission success standpoint because resulting unbalanced magnetic forces in the different sections of the magnet may cause it to deform, making it unable to be recharged to the maximum field or even to return to a superconducting state, thus preventing the recharging of the magnet. This is a possible mission success critical failure, not a safety issue. Alterations in the magnetic field have already been accounted for in the safety assessment for nominal field strengths.

To protect the magnet from this condition, referred to as an unassisted quench, electronics have been designed that will detect the initiating condition and apply heat quench evenly throughout the magnet coils, causing the magnetic field to dissipate uniformly. This will prevent the heating from being isolated to a small section of the magnet, which could become damaged if the quench was uncontrolled. By performing an assisted quench, mission success criteria can be maintained. The Cryomagnet Self Protection (CSP) section of the CAB was developed to detect a change in voltage across a coil and perform this assisted quench.

The CSP contains quench detection electronics that monitor the status of the magnet coils to determine if a quench condition is starting to occur. To perform this function, redundant voltage measurements are taken across each coil. If a quench condition is imminent, a voltage will develop across the affected coil. When the CSP detects a change in voltage, the quench protection electronics issues a command to the Uninterruptible Power Source (UPS) to provide a pulse of at least 45A to quench heaters located throughout the magnet. The pulse, for a duration of 150 ms, is required to raise the entire magnet up to a non-superconducting state. This spreads the quench throughout the magnet and prevents isolated heating that could result in degraded performance.

The quench heater chains are redundant and supplied by two separate UPS systems. The chains are routed to alternate coils throughout the magnet. Both heater chains are nominally used by the CSP to control a quench, however either chain independently is sufficient to protect the magnet coils from deformation.

The CSP provides additional functions to protect the magnet during off-nominal conditions. A “watch dog” timer, powered by the UPS, is continuously counting down. Periodically the timeout is reset via external command to about 8 hours. In the event of a power loss, or the loss of communication to the AMS-02 payload, the timeout is not reset and if power or communications are not restored to the AMS within the eight-hour period, the timer will trigger the CSP Control Electronics to initiate the nominal ramp down function, discharging the magnet. During the eight hour period and the ramp down, the UPS will continue to power the Quench Detection Electronics, and maintain the capability to perform an assisted quench (if necessary) until the magnet is completely discharged. The CSP, showing the cross-strapping configuration between the power busses coming from the PDS and the two batteries of UPS.

3.3.1.2.11.7 CSP Uninterruptible Power Source (UPS)

The UPS consists of dual redundant 28 Amp-hour (A-h) Lithium Ion Batteries and a Battery Management System (BMS) for each, developed by Yardney/Lithion Corporation, Pawcatuck, CT. Each battery consists of eight cells in series to generate the required nominal 28 Vdc for the system. To ensure mission success during loss of ISS power or communication, the UPS is required to supply power for the watchdog timer function, quench monitoring functions, nominal ramp-down at watchdog timer rundown, and initiation of a quench pulse of at least 45 A for 150ms anytime during the sequence.

Figure 3.3.1.2.11.7-1 shows the protection circuitry for the CAB Battery Charger Electronics (BCE), providing isolation between the UPS and PDS. The CAB BCE design includes the following protection electronics:

- Two double diodes in a cross-strapping configuration of the nominal and redundant 28Vdc primary power busses coming from PDS unit.
- SSPC (Solid State Power Conditioner), implemented by means of an Latching Current Limiter (LCL), which opens in case of failure.
- The HV power transformer barrier, which provides galvanic isolation between the electronics on primary side and the electronics on secondary side.
- The control electronics to provide the fit current to the battery, and also includes a power transformer with galvanic isolation.
- The blocking diode included in the BMS Battery Management System Electronics, which only permits the current way in only one direction.

All the above-mentioned protections included in the CAB BCE guarantee no propagation of failure to the ISS or any other unit, such as the PDS, which provides the 28Vdc primary power busses.

The CSP electronics design includes the following protection electronics between UPS and the loads (quench heaters, magnet valves):

- Two switches in series to power the quench heaters. These switches are only closed during 150ms of time required for the quenching sequence.
- SSPC (Solid State Power Conditioner), implemented by means of an LCL Latching Current Limiter, which opens in case of failure.
- The power transformer barrier, which provides galvanic isolation between the electronics on secondary side and the electronics on the load side.
- Two switches in series to open or close the valves.

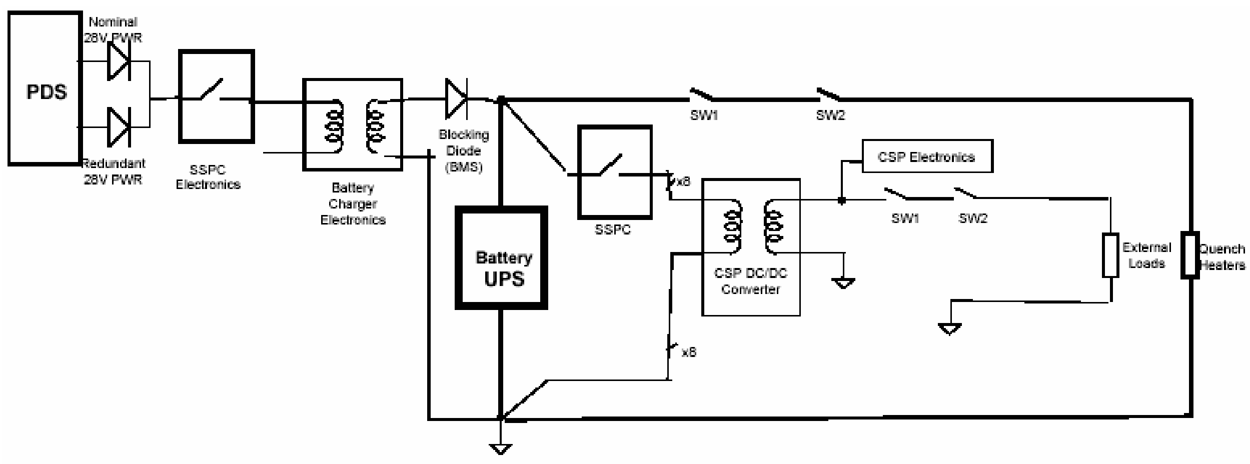


Figure 3.3.1.2.11.7-1 PDS to UPS Interface Diagram

3.3.1.2.11.8 Battery Management System

The Battery Management System (BMS) consists of four independent circuit boards and is designed to have the primary responsibility for battery condition (along with good design). The four boards consist of: a master controller board, two monitor/equalizer boards, and a protection/regulator board.

The BMS master controller board communicates with the two monitor/equalizer boards to obtain cell voltage and temperature. The master controller board uses this information to calculate the battery state of charge (SOC) for use in the charge algorithm and to control the battery pack cell equalization. In case of a critical hardware failure, such as loss of communication to the monitor equalizer boards, the master controller board determines this condition and activates the protection board or charger switch.

The two monitor/equalizer boards monitor cell voltage and pack temperature. They perform cell equalization on each charge cycle by resistively bypassing any cell with a voltage in excess of a predetermined maximum. The bypass current is dissipated through a resistor array on the board.

The master control board determines when the voltage condition is reached and activates the bypass. The master control board also determines when a cell voltage is exceeding allowable safety limits and activates the Protection and/or Charger switch as well.

The protection/regulator board is used to disconnect the pack from the load during fault conditions that include high cell temperature, low cell voltage and high current.

Additionally, a charger switch will disconnect the battery from the charger in cases of high cell temperature, high cell voltage or if the charger becomes uncontrollable. The switch will open in the case of a critical hardware failure, such as loss of communication to the monitor equalizer boards. The master controller board determines these conditions and sends the signal to the protection board or charger switch. The protection board employs multiple parallel metal-oxide-silicon field effect transistors (MOSFET) to carry the battery load current. Upon the occurrence of a short circuit the protection switch will open within 100msec (TBR) to isolate the battery from the short circuit condition.

Two sets of bricks and BMSs are mounted into a UPS box (Figure 3.3.1.2.11.8-1), apiece, which provide further containment and protection from MM/OD. Both UPS boxes are mounted to the USS in proximity to the CAB and the input port on the Vacuum Case to decrease line resistance (Figure 3.3.1.2.11.3-2).

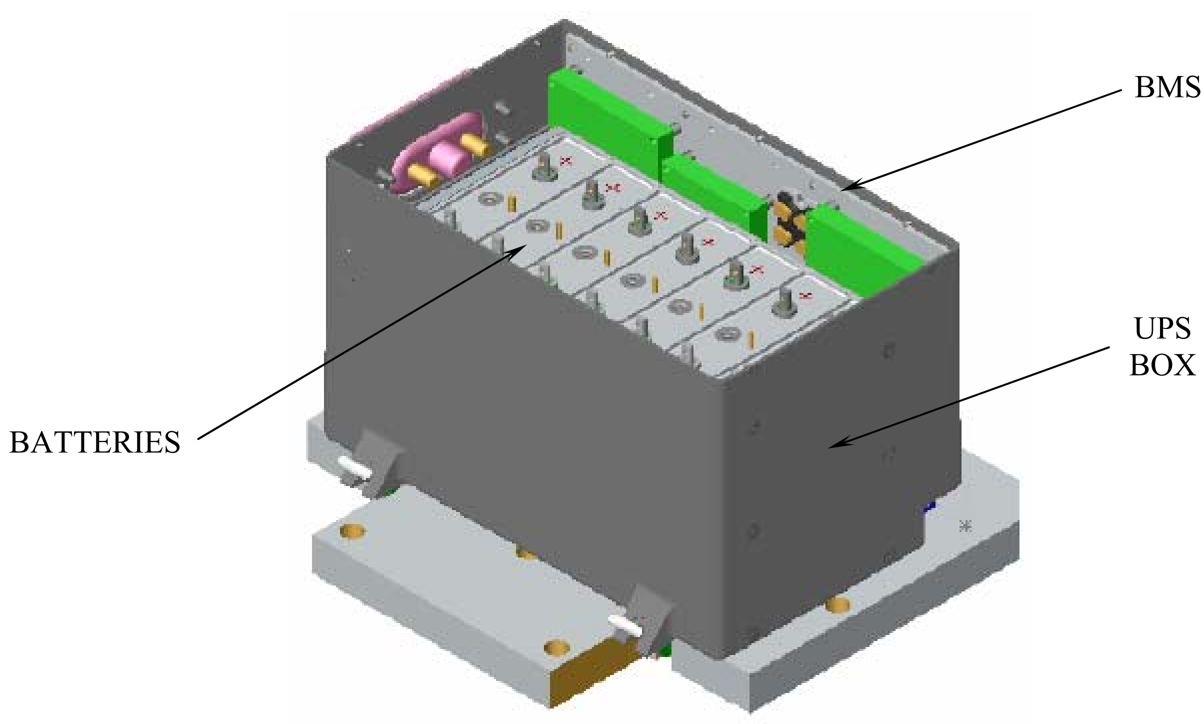


Figure 3.3.1.2.11.8-1 Battery and BMS mounted in UPS Box

3.3.1.2.11.9 Cryocooler Electronics Box (CCEB)

The CCEB receives 120 Vdc from either or both buses to power the Cryocoolers and their Monitor & Control Electronics. Bus-to-Bus isolation for the 120 Vdc is provided by relays. Over-current protection is provided by dedicated circuitry in eight power amplifiers. An SSPC in the PDS and fuses (TBR) in the CCEB provide additional circuit protection.

Monitor and Control Power for the CCEB is supplied by DC-to-DC converters operating from both buses (Figure 3.3.1.2.11.9-1). The DC-to-DC converters provide the necessary isolation bus-to-bus for the low voltage power.

Cryocooler power is routed from each bus through a set of four power amplifiers and passed through a power switch to each Cryocooler. The power amplifier consists of a 60-hertz pulse width modulated H-bridge with clamp logic, to improve efficiency and reduce electromagnetic interference (EMI). This provides the required drive signal for the Cryocoolers. The output of the power amplifier is then routed to the power switch. Each power amplifier has a current limiting circuit with a shutdown option.

The power switch contains inputs for the power amplifier signals from both buses. Four-pole, double throw relays select which bus each Cryocooler will be powered from. One pair of the poles are used to select the Hi and Lo signals from the selected power amplifier to power the Cryocoolers, and the other two poles are used for feedback of the relay position. Control of the power switch is provided by a Universal Slow Control Module (USCM), an AMS standard board with firmware used for control of low rate equipment. The USCM uses both ground command and automated configuration setting capabilities to control the Cryocoolers.

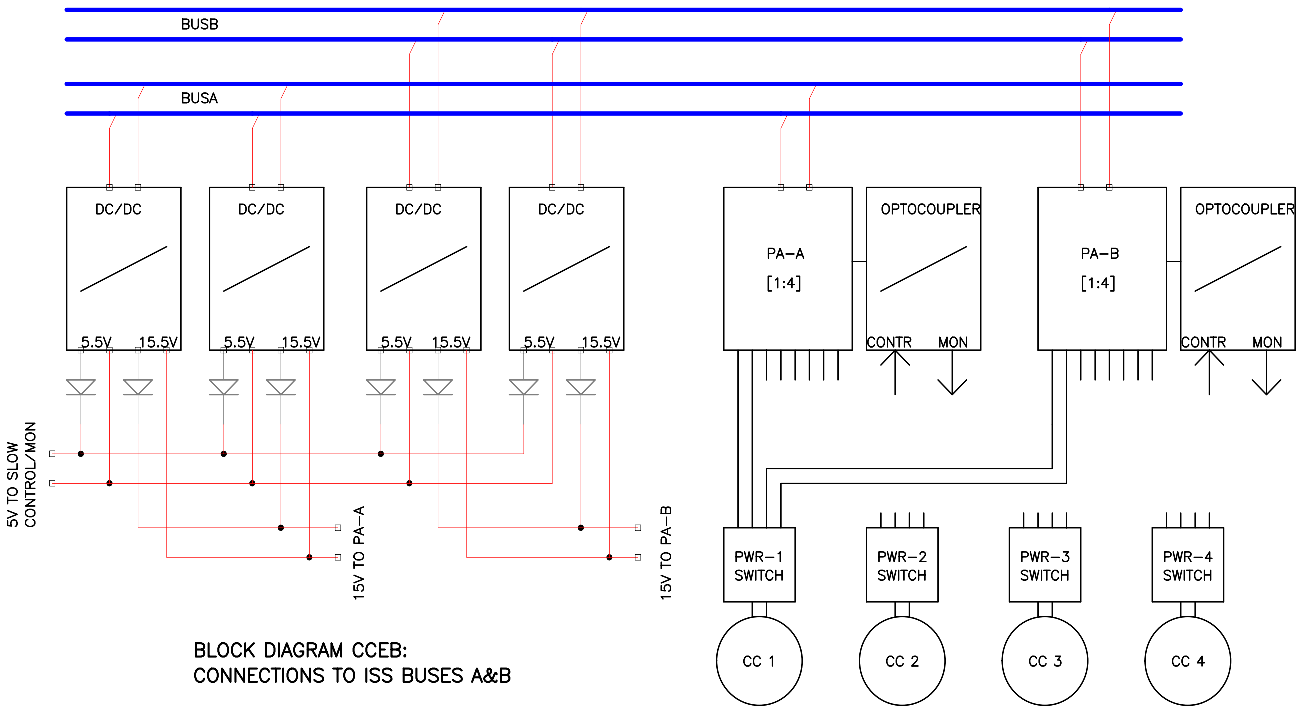


Figure 3.3.1.2.11.9 -1 Block Diagram of Cryocooler Electronics Box (CCEB)

3.3.1.2.11.10 OTHER ELECTRONIC BOXES? NOT IN SAFETY DATA PACKAGE – High Voltage Boxes.

3.3.1.2.12 Thermal Control System (TCS)

The AMS-02 Thermal Control System (TCS) is being developed and designed by the AMS experiment team. During nominal operations on ISS, AMS-02 draws up to 2600 watts of power. This power must be dissipated as heat, while maintaining all components within their temperature limits and maintaining the Vacuum Case as cold as possible. The payload also must be able to survive STS environments, handoff between STS and ISS, periods with no power (both during transfer and while berthed on ISS) and peak power excursions (e.g. magnet charging). Passive thermal design options are utilized as much as possible, but more complex thermal control hardware is required for some sub-detector components to assure mission success. TCS specific hardware includes radiators, heaters, thermal blankets, heat pipes, loop heat pipes, optical coatings and a dedicated CO2 pumped loop system for Tracker cooling. AMS-02 is designed such that passive thermal control is all that is required to sustain the payload safely through extended periods of power loss without hazard.

3.3.1.2.12.1 Ram and Wake Radiators

The Ram and Wake Main Radiators are designed to both dissipate heat from the electronics crates and provide their structural support. The crates, which are optimized to transfer heat to the radiator, are bolted directly to the honeycomb panel using threaded inserts. A silicone based thermal interface filler, Chotherm 1671, is used to minimize the thermal resistance across this interface. During nominal operations the Ram radiator dissipates 525 watts over its 4.24 m^2 surface area, while the Wake dissipates up to 812 watts over its 3.99 m^2 area. Heaters mounted on these radiators are used to bring electronics above their minimum turn-on temperature after periods without power. The outer surfaces of the radiator face sheets are painted with SG121FD white paint to optimize heat rejection. Portions of the crates and inner radiator surfaces are covered with MLI blankets to minimize heat rejection back to the vacuum case and to adjacent ISS payloads.

These radiators consist of a 25mm thick ROHACELL® core with 0.5mm thick 6061-T6 aluminum face sheets and imbedded heat pipes. A cross section is shown in Figure 3.3.1.2.12.1 -1. Heat pipe layouts are shown in Figures 3.3.1.2.12.1-2a & -2b. The heat pipes are standard axial groove, made of aluminum 6063 and filled with high purity ammonia. Each Main Radiator mounts to the USS-02 at six locations. Two brackets at the top fix the radiator to the Upper Trunnion Bridge Beams; two mid-brackets fix the middle portion of the radiator to the Lower Trunnion Bridge Beams and two pin-ended struts span the distance from the lower row of crates on the radiator to the Lower Vacuum Case Joint.

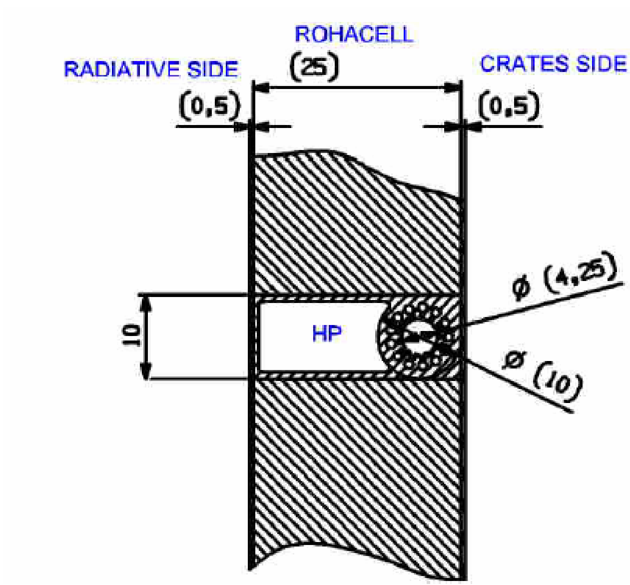
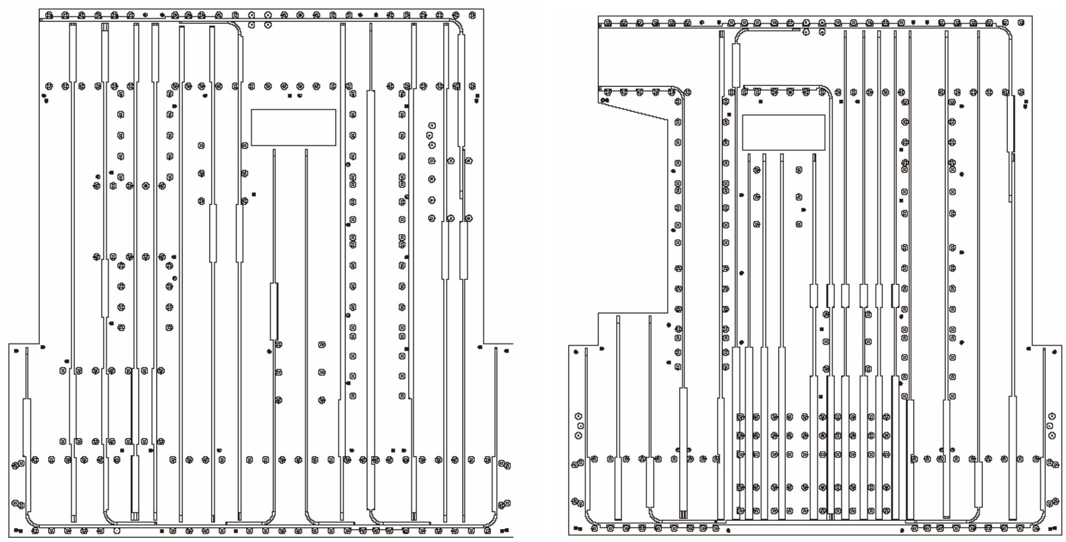


Figure 3.3.1.2.12.1 -1 Main Radiator Cross Section



a) Ram Main Radiator Heat Pipes b) Wake Main Radiator Heat Pipes

Figure3. 3.3.1.2.12.1-2 Ram and Wake Main radiator Heat Pipe Layout

3.3.1.2.12.2 Tracker Radiators

The Ram and Wake Tracker radiators are designed to reject the heat transported by the Tracker Thermal Control System (TTCS), a two-phase CO_2 loop running from inside the Tracker (~144 watts) to condensers mounted on the Radiators. Tracker radiators use Aluminum 2024 T81 face sheets with a ROHACELL® 52 core and imbedded aluminum/ammonia heat-pipes. The tracker radiators are trapezoidal, with a lower width of 2250 mm, an upper width of 2500 mm, and a height of 530 mm. 7 heat pipes are embedded in each Tracker Radiator. CO_2 loop condensers mount directly to the heat pipes by bolting through the radiator. Each radiator is mounted using 8 pin-ended struts; 1 attached to each of the Upper Trunnion Bridge Beams and 3 attached to each of the Upper Vacuum Case joint. There is also a bracket attaching each Tracker Radiator to the adjoining Main Radiator. The outer surfaces of the Tracker Radiators are painted with SG121FD white paint. The back sides will be covered with MLI blankets.

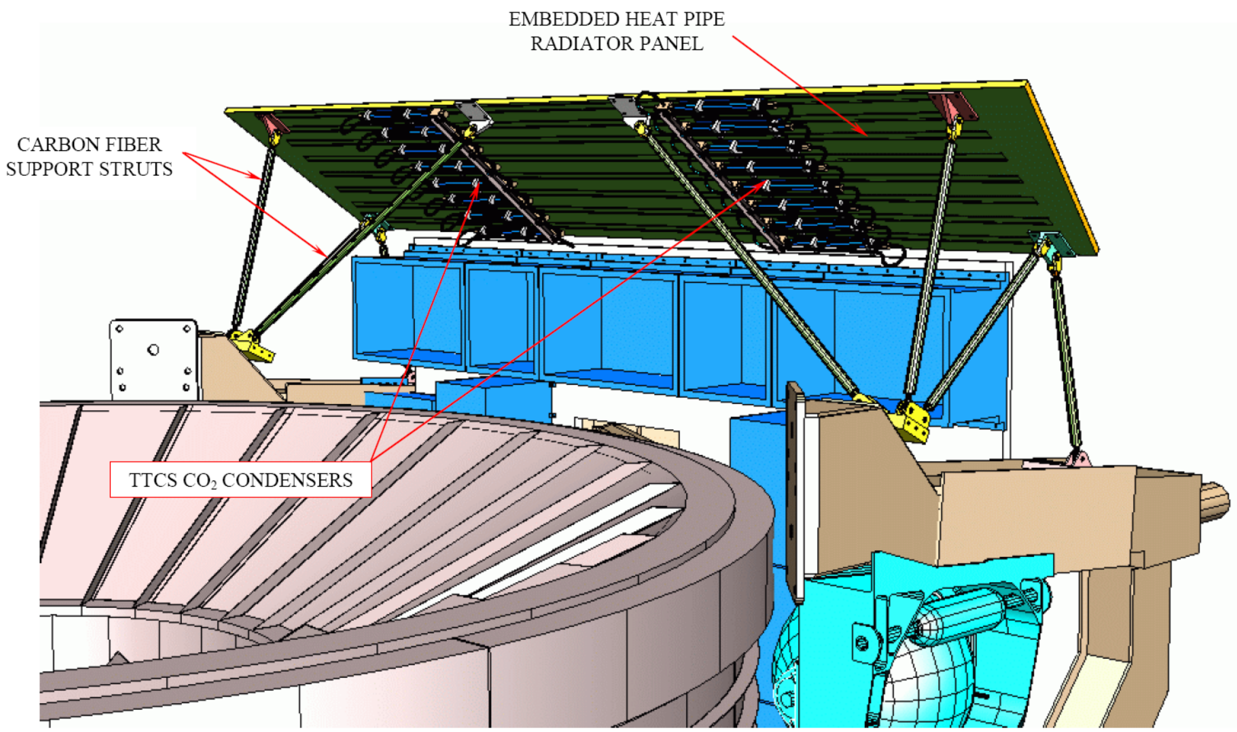


Figure 3.3.1.2.12.2-1 Tracker Radiators

3.3.1.2.12.3 Zenith Radiator

The Zenith Radiator actually consists of four separate panels, each design to reject heat (up to 150 watts) transported via two Loop Heat Pipes (LHPs) from a single Cryocooler (Figure 3.3.1.2.12.3-1). The radiator panels are constructed with aluminum 2024 T81 face sheets (1.6 mm for the upper face sheet and 0.3 for the lower), with a 10 mm ROHACELL® core. The condenser portion of each Loop Heat Pipes is a 4mm OD (3mm ID) aluminum 6063 tube, which is brazed to the upper face sheet of the radiator along a path designed to optimally reject heat. At the outer edge of each panel, the aluminum condenser tubes transition to stainless steel tubes via bimetallic joints. Each radiator panel is mounted to the top of the Upper TRD honeycomb panel via 14, 3mm OD x 35 mm long carbon-fiber pins, design to minimize heat leak, and two brackets; a Glass Fiber Reinforced Polymer (GFRP) bracket in the center and an aluminum one on the outer edge. The outer face of the Zenith Radiator is covered with Silver-Teflon film to maximize heat rejection capability. An MLI blanket is used on the under side to isolate the Zenith Radiator from the TRD.

Cryocooler cooling is achieved using two redundant Loop Heat Pipes (LHPs) to collect and transport heat from each of the four cryocoolers to a zenith-mounted, direct-flow radiator. The Loop Heat Pipes (along with the Zenith Radiators) are being built by IberEspacio of Madrid, Spain. The evaporator portion of each LHP is attached to a heat rejection collar on the cryocooler body. This bolted interface includes an Indium interface filler to minimize the thermal resistance. The LHP does not interface directly with the Cryomagnet pressurized systems.

Heaters are used for Cryocooler startup and to keep them above minimum storage limits. A control valve is used to redirect flow into a bypass loop if cryocooler temperatures start getting too cold. This valve uses a bellows system, filled with Argon at a predetermined pressure to control the direction of propylene flow. Each LHP is made primarily of stainless steel, with nickel wicks and high purity propylene as a working fluid. 3 mm stainless steel tubing runs to the edge of the radiator, where it is transitioned to aluminum tubing via a bi-metallic joint. As mention in the previous section, this aluminum tubing is brazed to the upper aluminum skin of the zenith radiators.

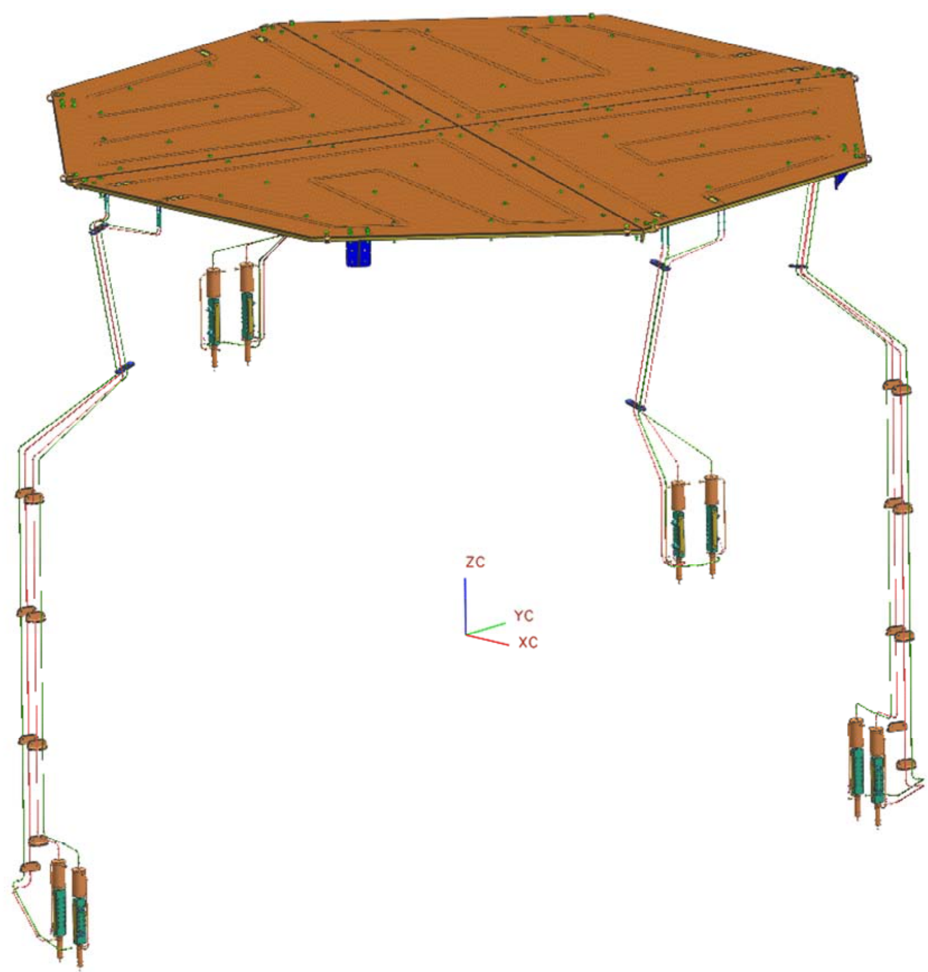


Figure 3.3.1.2.12.3-1 Zenith Radiator Panels

3.3.1.2.12.4 Multi-Layer Insulation (MLI) Blankets

AMS-02 will have numerous MLI blankets on various components and sub-detectors. Typical construction will include Beta cloth as the outermost surface, 5 to 20 layer of aluminized Mylar separated by Dacron scrim, and reinforced aluminized Kapton as an inner surface. All MLI blankets used on AMS-02 will meet or exceed the NASA requirements for grounding and venting.

3.3.1.2.12.5 Tracker Thermal Control System (TTCS)

The TTCS is the most complex thermal control system on the AMS-02, to reject heat from the Silicone Tracker system and provide a uniform temperature distribution across the Tracker Silicon sensor arrays. The Silicone Tracker, completely encased inside the inner bore of the Vacuum Case, generates 144 watts which need to be rejected while minimizing heat flow to the vacuum case inner cylinder. The TTCS thermal design includes thermal bars, a pumped CO_2 cooling loop, radiators, manifolds, accumulators and numerous other components to accomplish this controlled heat rejection.

3.3.1.2.12.5.1 TTCS Evaporator

Each of the 192 hybrid electronic boards or Hybrids, located on the periphery of 8 Tracker planes, generates 0.75 watts. There are 6 inner rings of Hybrids inside the Vacuum Case Inner Cylinder, 1 above and 1 below. The Hybrids are attached to thermal bars, frames made of Thermal Pyrolytic Graphite (TPG) encased in aluminum 6061. Between inner planes, the Thermal Bars are thermally connected to each other via flexible connecters made of copper. Thermal Bridges, also made of copper, connect the end thermal bars to the inner evaporator ring tube. Hybrids on the two Outer Planes connect to the outer ring evaporator tubes via copper braids. There is an Inner and Outer ring evaporator on both the upper and lower Tracker flange. For redundancy, all evaporators include two separate tubes connected to independent cooling loops.

3.3.1.2.12.5.2 TTCS CO_2 Cooling Loop

The TTCS cooling loop uses carbon dioxide to pick up heat from the evaporator rings inside the Silicone Tracker. The CO_2 transports heat to condensers connected to radiators on both ram and wake sides of AMS. Fluid is transported back to the evaporator by means of a mechanical pump. Condensers and radiators are design to assure that the CO_2 is sufficiently cooled so that only liquid will enter the pump.

To maintain the Tracker as isothermal as possible, two-phase cooling is desired throughout the evaporator. This is achieved by using an electric heater to pre-heat the fluid to the saturation temperature before it enters the evaporator. To minimize required heater power, a heat exchanger connects the evaporator inlet and outlet near the electric pre-heater. Figures 3.3.1.2.12.5.2-1 and 3.3.1.2.12.5.2-2 show schematics of the Primary and Secondary TTCS Cooling Loops. The loops are identical except that the Primary Loop includes a small independent experiment, an Oscillating Heat Pipe (OHP), which will be described later, and four balancing valves used to adjust performance of the primary loop.

For each loop, the pump, accumulator, heat exchanger, pre-heater and valves are located in the Tracker Thermal Control Box (TTCB) shown in Figure 3.3.1.2.12.5.2-3. The Oscillating Heat Pipe is also located in the Primary TTCB. The Primary TTCB is mounted on the +X +Y Lower Trunnion Bridge Beam while the Secondary is mounted to the –X +Y Lower Trunnion Bridge Beam. The boxes are thermally isolated from the beams and covered with an MLI blanket, except for the Wake facing surface which is used as a radiator.

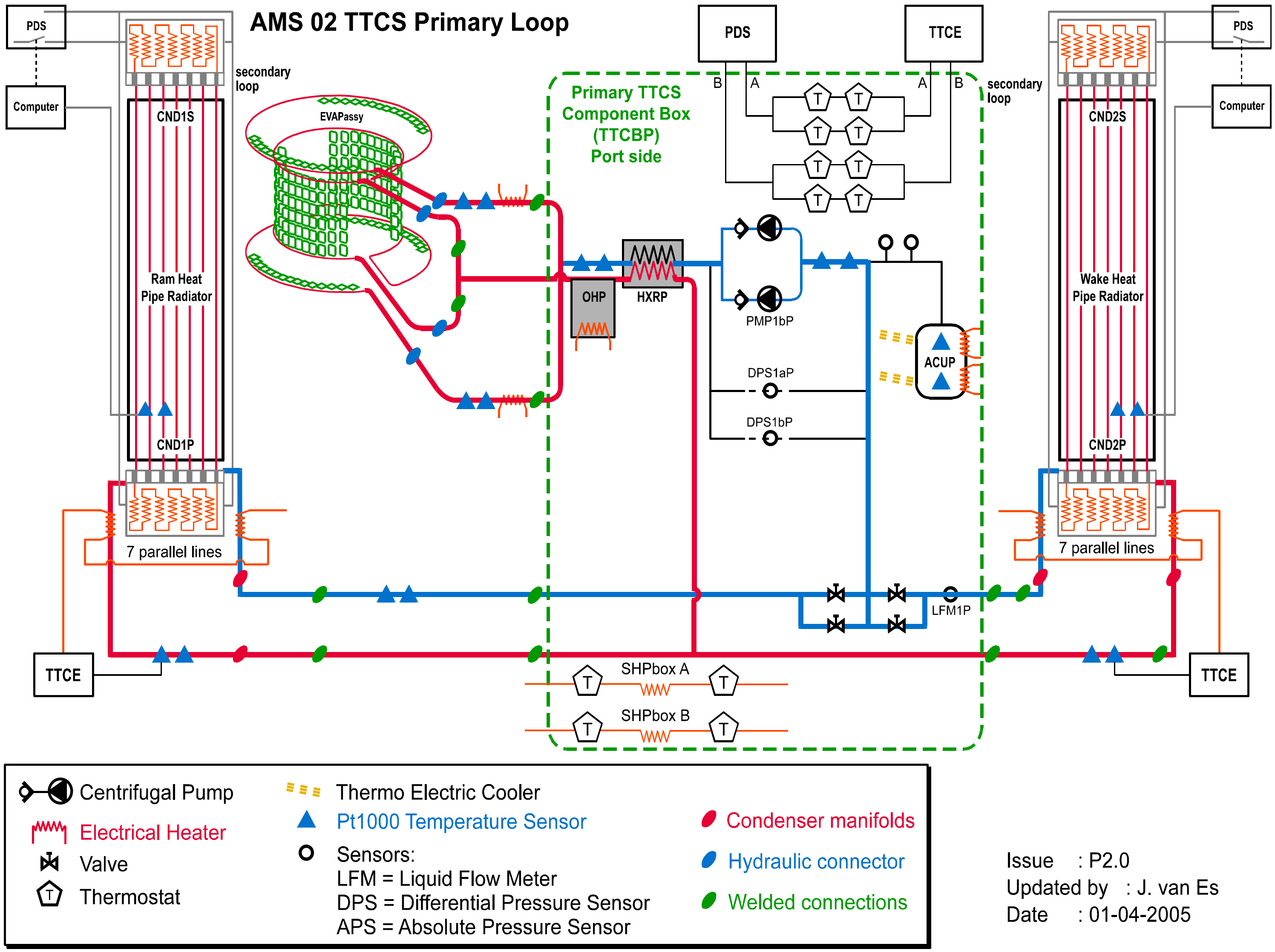


Figure 3.3.1.2.12.5.2-1 AMS-02 Tracker Thermal Control System Primary Loop

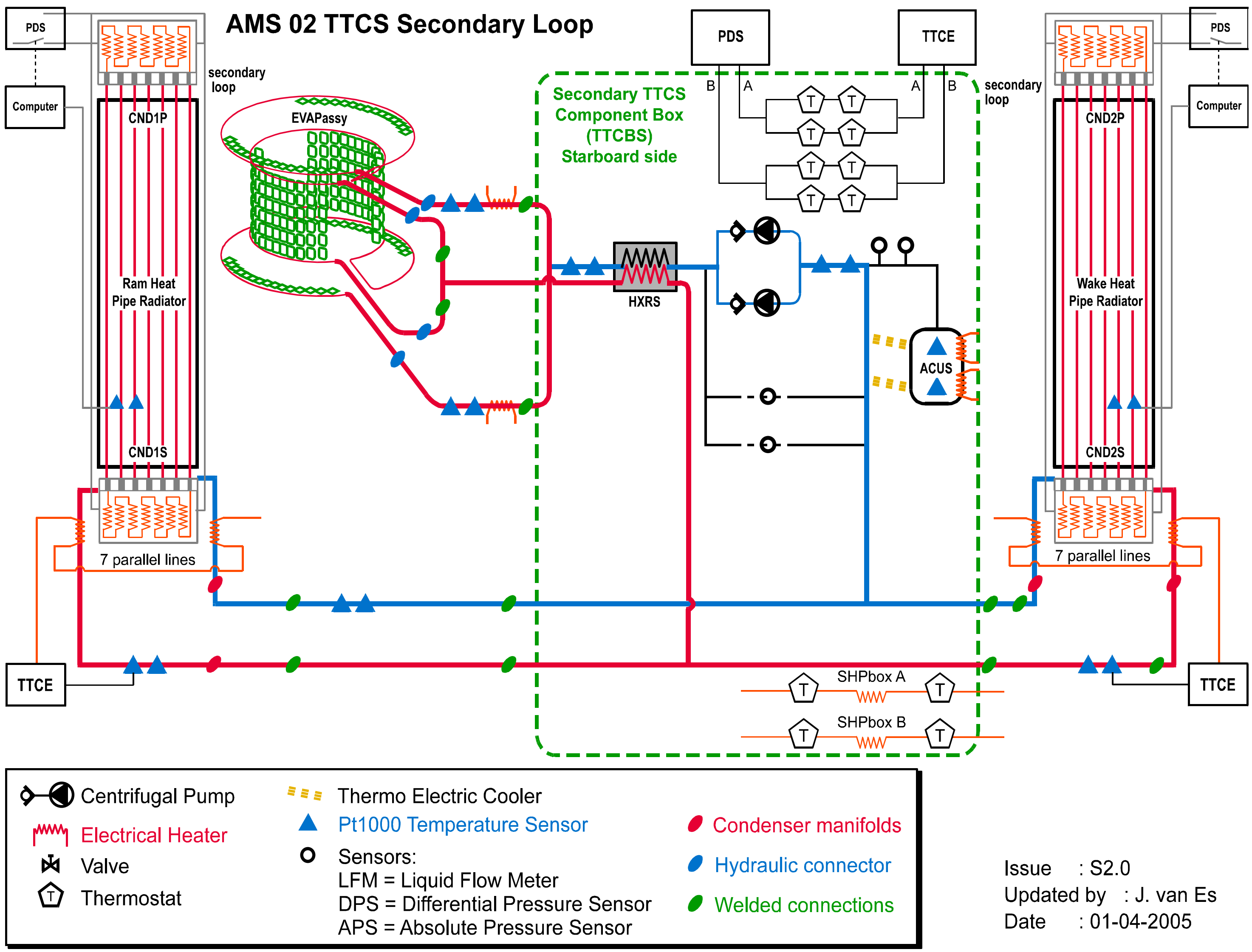


Figure 3.3.1.2.12.5.2-2 AMS-02 Tracker Thermal Control System Secondary Loop

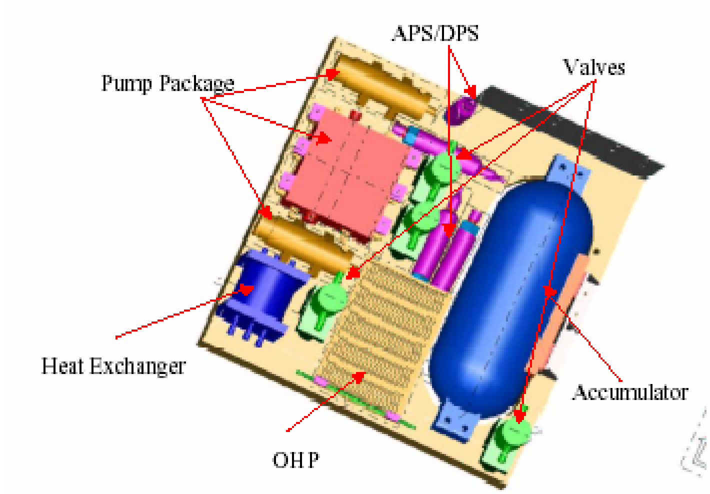


Figure 3.3.1.2.12.5.2-3 TTCB

3.3.1.2.12.5.3 Condensers

There are 14 TTCS condensers mounted on both the Ram and Wake Tracker Radiators. Pairs of condensers are thermally connected to each of the 7 heat pipes embedded in each radiator. Mounting is achieved by bolting through the radiator with Chotherm 1671 used as a thermal interface filler.

The condenser is constructed with 7 parallel lines of capillary tubing made of Inconel 718, soldered to an aluminum plate (Figure 3.3.1.2.12.5.3-1). Inconel tubing (1mm ID) also runs from the condensers to manifolds mounted on the Vacuum Case conical flange. The manifold combines the parallel flow from the capillary tube and transitions it to 2.6 mm ID stainless steel tubing. The condensers (including all capillary tubes) are designed to withstand freezing and thaw of CO_2. Heater wires are mounted on the capillary tubes to thaw the lines in case of freezing after loss of power.

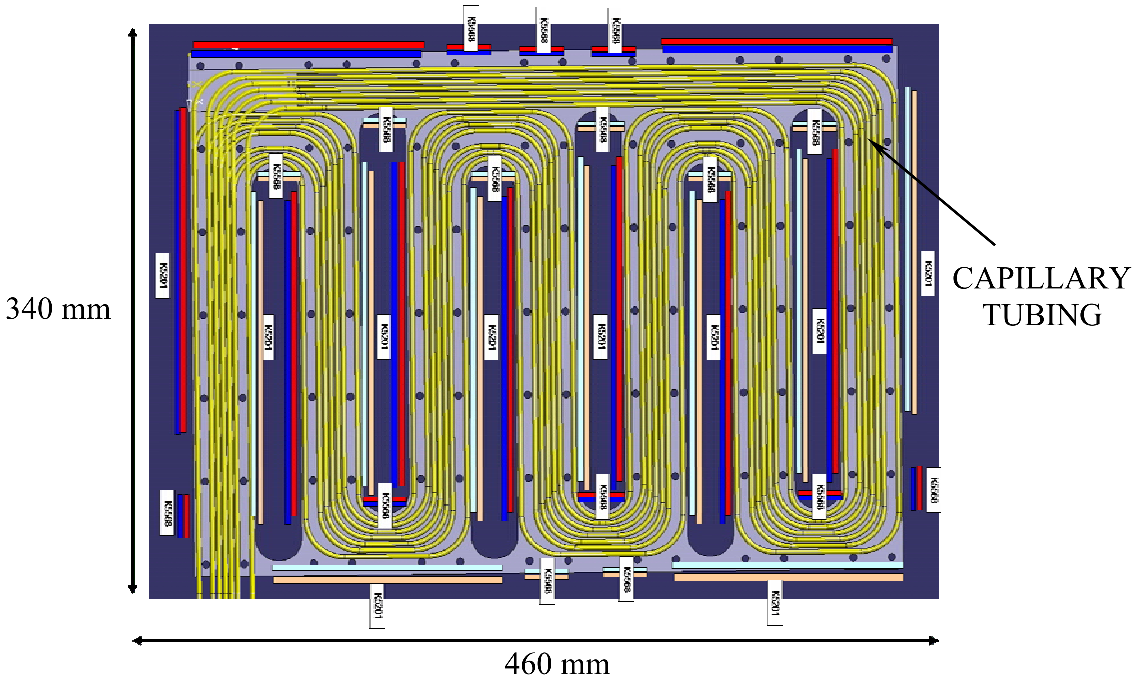


Figure 3.3.1.2.12.5.3-1 TTCS Condenser

3.3.1.2.13 Micrometeoroid and Orbital Debris (MMOD) Shields

The MMOD will be designed, analyzed, built and integrated by NASA/ESCG. The shielding is designed to protect the pressure systems on the AMS-02 experiment according to the environments specified in SSP 30425, paragraph 8.0. These systems include the Vacuum Case, Warm Helium Supply, and the TRD Gas System which contains both the Xe tank and CO_2 tank.

The shielding will be made from various components in different locations depending on the required shield thickness, shape and size. The MMOD shielding for AMS-02 consists of a 0.1 inch outer and inner aluminum sheet with a layer of 0.1 inch Kevlar/Nextel. Standoffs will be used to separate the outer aluminum sheet from the inner aluminum sheet. The shield design is shown in figure 3.3.1.2.13-1. Both sets of MMOD shields will have the same general design.

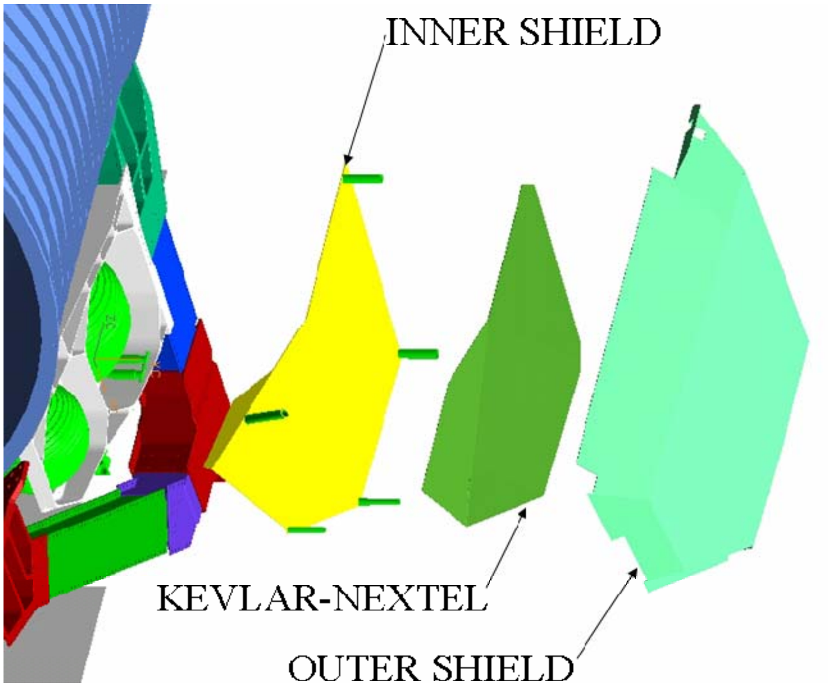


Figure 3.3.1.2.13-1 MMOD Shield Design

The shield assemblies will be bolted to the Upper and Lower Trunnion Bridge Beams of the USS-02.

3.3.1.2.14 Digital Data Recording System – 02 (DDRS-02)

The DDRS-02 utilizes a standard Space Shuttle Program Provided PGSC and a dedicated Digi International DataFire Sync 570I PCI, two port, Universal Interface Bus Card and DataFire Sync 570I to PDIP Cables (2 data cables) to interface with the Orbiter provided data port.

3.4 AMS-02 GROUND SUPPORT EQUIPMENT

This section should include descriptions of any major GSE that is used during the verification (proof of shalls) process.

3.5 OTHER ARCHITECTURE DESCRIPTIONS

This section should contain any other relevant architecture descriptions that are necessary to understand the overall verification process. For example, the AMS-02 power architecture, C&DH architecture, etc.

4. Verification Process

The following subparagraphs detail the verification process in terms of management responsibilities and methodology.

4.1 VERIFICATION MANAGEMENT RESPONSIBILITIES

4.2 AMS-02 ROLES AND RESPONSIBILITIES

The Implementing Arrangement (IA) between the Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA) establishes the roles and responsibilities of DOE and NASA with respect to the Alpha Magnetic Spectrometer (AMS) Program.

4.2.1 NASA Responsibilities

NASA Headquarters is responsible for the overall NASA management of the AMS Program interface activity between NASA and DOE and for overall program management of the NASA activities required to support the implementation of the flight of AMS-02 (Figure 4.2.1-1). The AMS Project Office (APO) of the Engineering Directorate (EA) at JSC has been assigned responsibility for implementing the AMS Program. The APO serves as the AMS representative and acts as the single point of contact between the AMS Program and the Shuttle and ISS Programs. The APO reports and is responsible directly to NASA Headquarters and is the AMS NASA representative to all other NASA organizations providing equipment, materials, and services to the AMS Program.

In order to implement the AMS Program, NASA will perform or provide the following:

- Fly the AMS-02 on the ISS as an external attached payload, and provide accommodation on the ISS; all necessary services, AMS-to-carrier integration, AMS transfer to and installation on the ISS. NASA shall include the AMS-02 in the Space Station utilization planning process.

- Provide mission-peculiar interface hardware and software for the AMS-02 on the ISS.

- Perform AMS-to-carrier integration support, payload certification, and payload safety certification.

- Provide necessary facilities and perform related services for the AMS-02 final assembly, testing and checkout at the launch site, as well as control center accommodations for AMS-02 operation and monitoring as required for the launch and transfer-to-ISS phases.

- Provide AMS-02 housekeeping, science (unprocessed) and carrier-ancillary data products to the DOE-sponsored team at the designated NASA data handling/distribution center.

- Perform a mission management function consisting of the following tasks in support of AMS:

    - Representation of the AMS to the Shuttle Program, the ISS Program, and to various supporting NASA organizations involved in the integration and flight of AMS.
    - Design and operations consulting and guidance to the AMS Program to minimize the potential for incorporation into the AMS design of features or characteristics which could result in functional and/or safety incompatibilities with either the Shuttle or the ISS or with ground systems at the launch or landing sites.
    - Performance of detailed engineering analyses (e.g. stress, loads, etc,) to ensure compatibility of the AMS with the Shuttle and ISS through its launch, operational, and return environments.
    - Systems engineering for the development of mission-peculiar interface hardware and software needed to analytically, physically, and operationally integrate the AMS into the Shuttle and ISS system.
    - Management of the physical integration of the AMS and mission-peculiar interface hardware onto the Shuttle and ISS carriers.
    - Guidance, identification and control of hazards, and lead role in development of Safety Compliance Documentation, and representation of AMS to the Shuttle, ISS, and KSC Safety Panels.
    - Guidance in the development of requirements levied on the Shuttle and ISS and lead role in negotiation of those requirements through the Shuttle Payload Integration Plan, (PIP), the ISS PIP, the associated annexes, and required Interface Control Documents (ICDs).
    - Provision of training related to Shuttle and Station operations, including the development of training requirements.
    - Provision of documentation required for payload verification of AMS compliance with Shuttle and ISS program requirements.
    - Representation of the AMS Program at KSC and support of testing, AMS-to-carrier integration, and flight operations.
    - Real-time mission support for the delivery flight to the ISS, through AMS deployment, installation, checkout, and verification of proper operation.

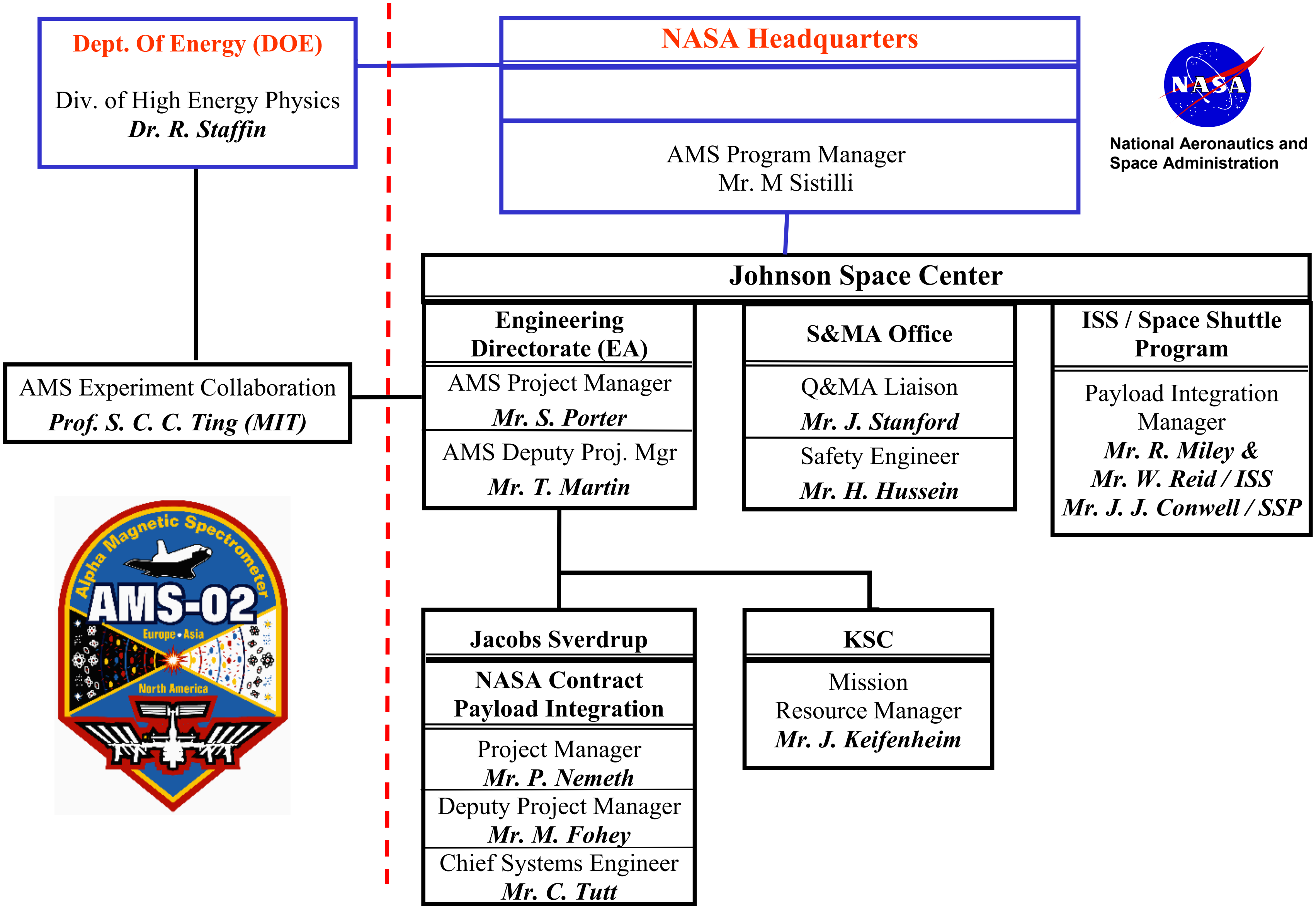


Figure 4.2.1-1 AMS Project Functional Organization

Flight hardware to be provided by NASA/APO is listed in Table 4.2.1-1.

TABLE 4.2.1-1 NASA/APO PROVIDED FLIGHT HARDWARE

ITEM	QUANTITY
* External Berthing Camera System (EBCS), w/cables and brackets	1
* EVA (Extravehicular Activity) Handrails/ Tether Attach Points	9
* Flight Releasable Grapple Fixture (FRGF), w/cables and brackets	1
* Portable Foot Restraint (PFR) Worksite Interface Fixture (WIF)	1 (or 2 if required by ROEU redesign)
* Power Video Grapple Fixture (PVGF), w/cables and brackets	1
* Remotely Operated Electrical Umbilical (ROEU)/Payload Disconnect Assembly (PDA), w/cables and brackets	1
* Umbilical Mechanism Assembly (UMA) (Passive Half), w/cables and brackets	1
Cryomagnet Vacuum Case (VC) (Flight Article)	1
Micrometeoroid and Orbital Debris (MMOD) Shields	2
Payload Attach System (PAS) (Passive Half)	1
EVA Interface Panel (Interface to UMA)	1
Interface Panel A (Interface to ROEU)	1
Cabling from interface panels to J-Crate and PDS	as required
DDRS–02 and associated cabling/interface cards	1
Trunnion scuff plates for deployable payload	4 (Part of USS-02)
Thermal Blankets	6
Unique Support Structure-02 (USS-02)	1

* Items (excluding brackets) supplied by NASA SSP or ISSP and integrated into AMS Payload by NASA/APO.

4.2.2 DOE Responsibilities

The DOE Headquarters Division of High Energy Physics, under the Department's Office of Energy Research is responsible for the administration of a Cooperative Agreement with the Massachusetts Institute of Technology (MIT) for a basic science program in particle physics. Under this agreement, the MIT Principal Investigator for the AMS Program has organized, and is the spokesman for, the AMS International Collaboration, currently consisting of over 200 physicists from 16 countries, to implement its part in the AMS Project (Figure 4.2.2-1). The DOE or, as appropriate, its MIT Cooperative Agreement Principal Investigator, will be responsible for: the definition, design, and development of the AMS hardware and related ground support equipment (GSE); delivery to and return from a location to be specified at the Kennedy Space Center (KSC) for integration or de-integration in the NASA processing system; and establishment of the science mission requirements. These responsibilities will include:

- All necessary interagency coordination and obtaining necessary concurrences within the U.S. Government for the AMS Project regarding international arrangements among the DOE Program Collaborators involved in the definition, design, development, fabrication, assembly, test, checkout, and operation of the AMS.
- Management of all international transfer and shipment, unless otherwise agreed. This includes, but is not limited to, customs clearances, import and export licenses required for AMS systems, subsystems, or components, or, as mutually agreed, for any NASA tests, integration, or mission-peculiar equipment or technical data that is required to be shipped abroad.
- Establishment of the AMS science plan, including science requirements, definition of data requirements, and definition of mission success criteria.
- Provision, when requested by NASA, of DOE technical and management support for all formal NASA reviews involving AMS (Safety Reviews, Cargo Integration Reviews, Ground Operations Reviews, Flight Operations Reviews, etc.) and other related NASA reviews and activities.
- Development and management of an AMS implementation schedule consistent with NASA program milestone schedules and provision of updates to keep NASA advised of AMS schedule status.
- Provision of technical and management data required by NASA to complete programmatic requirements (e.g. Safety, ICDs, MIP, reviews, material lists, etc.).
- Provision of all transport equipment (shipping containers, other AMS handling ground support equipment) required for AMS transport to and from NASA KSC.
- Management of: (1) All AMS science and engineering team activities, including travel, visa issuances, and related in-country logistical expenses; (2) support for science operations before, during, and after AMS flights; and (3) science data analysis, distribution, and publication.

Flight hardware to be provided by DOE/MIT is listed in Table 4.2.2-1.

TABLE 4.2.2-1 DOE/MIT PROVIDED FLIGHT HARDWARE

ITEM	QUANTITY
Cryomagnet System including SFHe Tank, Non-linear Support Straps, and Cryomagnet Avionics Box (CAB)	1
Transition Radiation Detector and associated Gas System (TRD)	1
TRD Gas System	1
Upper and Lower Time-Of-Flight (TOF) Scintillator Assembly	1 each
AMS-02 Silicon Tracker Assembly	1
Tracker Alignment System (TAS)	1
Anti-Coincidence Counters (ACC)	1
Ring Imaging Cerenkov Counter (RICH)	1
Electromagnetic Calorimeter (ECAL)	1
Thermal Control System (TCS)	1
Star Tracker	2
Global Positioning System (GPS) Receiver	1

4.2 VERIFICATION METHODS

Each performance and design requirement of the AMS-02 hardware and software specifications is assigned a method for verification in the requirement verification matrix of this MVP. Four methods are used to satisfy verification requirements: analysis, inspection, demonstration, and test, or a combination of these. As the specification is developed, each requirement is analyzed and assigned a method that is documented in the verification matrix. This matrix thus provides the foundation for all further verification planning for that item. The assigned method may prove invalid as the design matures. In this case, the verification method will be updated in the verification matrix through normal document control channels, with the appropriate approvals.

4.2.1 Analysis

Analysis is a verification method utilizing techniques and tools such as math models, prior test data, simulations, analytical assessments, etc. Verification by similarity is acceptable if the subject article is similar or identical in design, manufacturing process, and quality control to another article that has been previously verified to an equivalent or more stringent criteria.

Examples of verification by analysis include thermal analysis and stress analysis to show that the use of the hardware does not exceed specification limits during the mission operation.

4.2.2 Inspection

Inspection is a method of verification of software code or hardware physical characteristics that determine compliance without the use of special laboratory equipment, procedures, test support items, or services. Inspection often uses visual methods to verify compliance with design requirements. A record of the inspection (TPS, weld inspection record, etc.) is required.

Examples of verification by inspection include verification of surface finish, elimination of sharp edges, software code evaluations and drawing evaluations.

4.2.3 Demonstration

Demonstration is a qualitative method of verification that evaluates the properties of the subject end item. Demonstration is used with or without special test equipment or instrumentation to verify required characteristics such as operational performance, human engineering features, service and access features, transportability, and displayed data. A formal record of demonstration (TPS) is required.

One example of verification by demonstration is verifying displays are legible when viewed through a helmet visor.

4.2.4 Test

Test is a method of verification wherein formal project hardware, software and firmware requirements (performance, environment, etc.) are verified by measurement or functional test during or after the controlled application of functional and/or environmental stimuli. These measurements may require the use of laboratory equipment, recorded data, procedures, test support items, or services. Examples include vibration testing and thermal/vacuum testing. Different types of testing that may be included in this section are qualification, acceptance, system integration, program integration, major ground testing, orbital flight demonstrations, pre-launch checkout, and on-orbit checkout.

Of note, when the results of any testing are intended for use in the formal verification of the project's products (i.e., verification of requirements listed in Appendix C), the test must be performed on controlled hardware/software, using only controlled and approved GSE, and must be documented (Task Performance Sheets, Discrepancy Reports, Test Reports or equivalent).

4.2.4.1 Qualification Testing

Qualification testing is performed on units that are identical to the flight articles but are not intended for flight, i.e. a qualification unit. The purpose of qualification tests is to ensure the design of the project's deliverables meet the environment (thermal, pressure, radiation, vibration, etc.) requirements imposed on the deliverable. These tests may exceed the expected induced environment levels. Qualification testing proves that an end item's design is adequate to meet the environment specification requirements. This testing will include functional tests before and after exposure to the test environment to determine the success or failure of the test. Depending on the project requirements, this may also include functional and performance tests being conducted during the environment tests.

4.3 VALIDATION METHODS

Validation is performed to ensure that, regardless of any specific set of requirements, the customer/sponsor will be satisfied with the product provided. Validation ensures the purpose of a system is not lost in the specification of the detailed requirements. Validation provides a means to confirm with the customer/sponsor to determine whether the product will meet their expectations. When performed early in the project, validation prevents wasted time and effort resulting from misunderstandings and wrong assumptions.

The same four methods can be used to perform validation: analysis, inspection, demonstration, and test, or a combination of these. The validation activities are negotiated with the customer/sponsor and are documented in a validation matrix (see Appendix D).

4.4 CERTIFICATION PROCESS

The Project Manager provides evidence to JSC SR&QA that the AMS-02 satisfies all performance and design requirements. The verification products provide the basis for this certification and may be supplemented with any validation products. Based on this evidence, JSC SR&QA approves the request for certification. This process is an audit of how the project has verified each requirement in Appendix C.

4.5 ACCEPTANCE TESTING

Acceptance testing is used to prove the flight unit(s) has replicated the certified design. These flight units are tracked by serial number (or software identifier). Acceptance testing is performed on each deliverable end item. In addition to proving the functionality of each unit at a selected subset of specification values, this testing also is intended to screen out manufacturing defects, workmanship errors, incipient failures and other performance anomalies not readily detectable by inspection. The acceptance testing process also ensures the verified firmware and/or software resident within the flight item has been properly installed.

Examples of functional acceptance tests include measurement of an output voltage level, proper software response, or a proper response to control stimuli. Examples of environment acceptance tests include vibration and thermal vacuum.

5. Verification Implementation

5.1 AMS-02 VERIFICATION FLOW

The AMS-02 verification process is broken down into three distinct categories: Requirements verification of the Payload Integration Hardware (PIH); Requirements verification of the Experiment Hardware; and Verification of the Phase II Safety Requirements. Verifications for each category are included in Appendix C – PIH, Appendix D – Experiment Hardware, and Appendix E – Safety Requirements. The AMS Project Office (APO) at JSC is responsible for the verifications contained in Appendices C and E. The AMS Collaboration is responsible for the verifications contained in Appendix D.

5.2 TEST ARTICLES

The AMS Project has built a structural test article (STA) Vacuum Case for verifying welding parameters and the structural integrity of the cryomagnet system including the support straps for the cold mass (cryomagnet, SFHe tank, etc.). The STA and the flight article were fabricated in parallel paths and as such are identical in every way. Mass simulators will be used to simulate the mass of the magnet and tank during the static, modal and acoustic testing of the integrated system. For all other testing of the integrated payload, the actual flight hardware will be used. As an example, an Interface Verification Test (IVT) was performed at KSC where the AMS-02 Passive PAS flight article was mated to the actual Active PAS on the S3 Truss to verify the interface and perform verifications of the EVA-releasable Capture Bar on the Passive PAS.

In most cases the Collaboration has taken the approach, when designing the experiment hardware, of building an engineering model (EM) and qualification model (QM) for evaluation, testing and certification before building the flight model (FM). In rare instances when schedules and/or budgets were tight, the Collaboration, with concurrence from NASA, has shortened the design effort by building a "proto-flight" unit to be used for qualification testing and for flight.

5.3 SUPPORT EQUIPMENT

In conjunction with the flight hardware, the AMS Project has designed and built a vacuum case test fixture (VCTF) as an interface between the STA Vacuum Case and the sine sweep test device. A test fixture that was used for AMS-01 is being modified to accommodate the wider trunnion spacing on the AMS-02 Payload. This test fixture will be used for the modal and static testing of the full-up payload. The Collaboration is responsible for designing and building a test stand for use at CERN for beam testing of the payload. The test stand will be capable of turning the payload 90 degrees to the horizontal position for performing the beam test.

5.4 FACILITIES

The major testing of the AMS-02 Payload is being conducted at various sites throughout Europe. Sine Sweep Testing of the STA is being conducted at an INFN facility in Terni, Italy. Sine Sweep Testing is tentatively scheduled for August 2006. Acoustic Testing of the STA is being conducted at ESTEC in Noordwijk, The Netherlands. Static and Modal Testing of the full-up payload is being conducted at IABG in Munich, Germany. Beam testing of the payload is being conducted at CERN in Geneva, Switzerland.

6. AMS-02 Certification Products

This section should summarize the certification products/package that will be provided by the project. The package may vary with the project, but the certification data package should include the following types of products:

1. *Government Certification Approval Request (GCAR, form 1296)*
   See http://www.srqa.jsc.nasa.gov/gcars/gcar.htm for additional information and instructions)
2. Safety Data Package (see Sections 7.1.4.2, 7.1.5.2 and 7.1.6.2)
3. The revision of the MVP, with the "Results" column of the appendices completed and associated "Results" documentation attached.
4. Materials Certification
5. Fracture Control Report
6. Materials Usage Agreement
7. Stress Analysis
8. Thermal Analysis
9. EEE Parts Stress Analysis/De-rating Analysis
10. Qualification Test Reports
11. Waivers
12. Limited Life Items List
13. Engineering Drawings (electronic or hardcopy as required by NT-GFE-007, "Certification Approval of JSC GFE")
14. Software/Firmware Version Description Document (VDD) (see EA-WI-025)

APPENDIX A - ACRONYMS AND ABBREVIATIONS

ACC	Anti-Coincidence Counter
ACOP	AMS Crew Operations Post
AMS	Alpha Magnetic Spectrometer
APCU	Assembly Power Converter Unit
CAB	Cryomagnet Avionics Box
CCB	Configuration Control Board
CCEB	Cryocooler Electronics Box
CDD	Cryomagnet Dump Diodes
CDR	Critical Design Review
CG	Center of Gravity
cm	centimeter
CMR	Cold Mass Replica
COTS	Commercial Off-the-Shelf
CR/DIR	Change Request/Directive
DC	Direct Current
DDRS-02	Digital Data Recording System-02
DOE	Department Of Energy
EA	JSC Engineering Directorate
EBCS	External Berthing Cue System
ECAL	Electromagnetic Calorimeter
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESCG	Engineering and Science Contract Group
EVA	Extravehicular Activity
EXPRESS	EXpedite the PRocessing of Experiments to Space Station
F	Fahrenheit
FOR	Flight Operations Review
FPSR	Flight Planning And Stowage Review
FRGF	Flight Releasable Grapple Fixture

APPENDIX A ACRONYMS AND ABBREVIATIONS (Continued)

FRR	Flight Readiness Review
g	gram (also gravity)
G	Gravity (also g)
GFE	Government Furnished Equipment
GHE	Ground Handling Equipment
GSE	Ground Support Equipment
He	Helium
HRDL	High Rate Data Link
Hz	Hertz
ICD	Interface Control Document
IDD	Interface Design Document
in	inch
IPT	Integrated Product Team
ISS	International Space Station
ISSP	International Space Station Program
ITS	Integrated Truss Segment
JSC	Lyndon B. Johnson Space Center
K	Kelvin
kg	kilogram
KHB	KSC Handbook
KSC	John F. Kennedy Space Center
L	Liter (also l)
lbs	pounds
MAGIK	Manipulator Analysis, Graphics, and Integrated Kinematics
MIL	Military
MIT	Massachusetts Institute of Technology

APPENDIX A ACRONYMS AND ABBREVIATIONS (Continued)

MLI	Multi-layer Insulation
MM/OD	Micrometeoroid and Orbital Debris
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NBL	Neutral Buoyancy Laboratory
NHB	National Aeronautics and Space Administration Handbook
NSTS	National Space Transportation System
PAS	Payload Attach System
PCS	Portable Computer System
PDA	Payload Disconnect Assembly
PDIP	Payload Data Interface Panel
PDR	Preliminary Design Review
PDS	Power Distribution System
PFR	Portable Foot Restraint
PIH	Payload Integration Hardware
PSS	Primary Support Stand
PVGF	Power Video Grapple Fixture
RICH	Ring Imaging Cherenkov Counter
ROEU	Remotely Operated Electrical Umbilical
S&MA	Safety and Mission Assurance
SCSI	Small Computer Systems Interface
SFHe	Superfluid Helium
SPEC	Specification
SRMS	Shuttle Remote Manipulator System
SSP	Space Station Program
SSRMS	Space Station Remote Manipulator System
STA	Structural Test Article
STD	Standard
STE	Special Test Equipment

APPENDIX A ACRONYMS AND ABBREVIATIONS (Continued)

STS	Space Transportation System
TBD	To be Determined
TCS	Thermal Control System
TOF	Time of Flight
TRD	Transition Radiation Detector
UMA	Umbilical Mechanism Assembly
UPS	Uninterruptible Power Supply
USS-02	Unique Support Structure-02
Vdc	Volts Direct Current
VAR	Verification Acceptance Review
VC	Vacuum Case
WIF	Worksite Interface Fixture

APPENDIX B - DEFINITION OF TERMS

Verification Terms

Certification: the audit process by which the body of evidence that results from the verification activities presented are provided to the appropriate certifying authority to indicate all requirements are met.

Deviation: Written authorization issued "before the fact" to develop a product that departs from established requirements.

HSI1: Hardware/software integration (HSI) that is performed prior to PDR. This testing establishes confidence that the hardware and software design concepts are adequate to meet functional interfaces.

HSI2: Hardware/software integration that is performed prior to CDR on engineering unit or DVTU hardware. This testing establishes confidence that the hardware and software detailed designs meets requirements.

Validation: the process that ensures a system meets the customer/sponsor's expectations for intended use. Unique validation activities may not be required if validation is satisfied through verification or acceptance testing activities.

Verification: a formal process, using the method of test, analysis, inspection or demonstration, to confirm that a system and its hardware and software components satisfy all specified performance and operational requirements.

Waiver: Written authorization to temporarily accept an item that departs from a particular performance or design requirement of a specification, drawing, or other contract document. The authorization is granted for a specific number of items and/or a specific period of time. The item(s) is/are considered suitable for use "as is" for a specified period of time or quantity of items, until reworked by approved method.

Types of Verification Methods

Test: a method of verification wherein formal project requirements (performance, environment, etc.) are verified by measurement or functional test during or after the controlled application of functional and/or environmental stimuli. These measurements may require the use of laboratory equipment, recorded data, procedures, test support items, or specialized software.

Analysis: a verification method utilizing techniques and tools such as math models, prior test data, simulations, analytical assessments, etc. Verification by similarity is acceptable if the subject article is similar or identical in design, manufacturer, manufacturing process, and quality control to another article that has been previously verified to equivalent or more stringent criteria.

Inspection: a method of verification of physical characteristics that determines compliance without the use of special laboratory equipment, procedures, test support items, or services.

Inspection uses standard methods such as visual gauges, etc. to verify compliance with design requirements.

Demonstration: a qualitative method of verification that evaluates the properties of the subject end item. Demonstration is used with or without special test equipment or instrumentation to verify required characteristics such as operational performance, human engineering features, service and access features, transportability, and displayed data.

Testing Levels

Development testing: subsystem or component level testing (including firmware/software testing) that is performed on end items in order to show that a specific design approach is acceptable for both functional and performance requirements. The tests may be performed on controlled or uncontrolled hardware components, software, or major configuration end items.

Qualification testing: performed on end items that are identical to the flight units. The purpose of qualification tests is to ensure the design of the project's deliverables meets the environment (thermal, pressure, vibration, etc.) requirements imposed on the deliverable.

Acceptance testing: used to show a specific end item, tracked by serial number, or unique firmware and/or software identifier, has successfully replicated the end item design. Acceptance testing is performed on each deliverable end item. In addition to proving the functionality of each unit at defined specification values, this testing also is intended to screen out manufacturing defects, workmanship errors, incipient failures, and other functional anomalies not readily detectable by inspection. The acceptance testing process also ensures the verified firmware and/or software resident within the system has been properly loaded into the appropriate end item.

System level testing: performed with all end items assembled and integrated together. Ensures that all items being provided by the project are compatible. May also include interface testing between the system and its immediate interfaces with other systems.

End-to-End testing: performed with not only the provided system but also all its other internal (vehicle) and external (ground, satellite, etc) interfaces. Basically, a test from initial bit generation on-board to the end user whether that occurs on-board or on the ground (MCC, customer/sponsor center, etc).

Types of Test Articles

Prototype Unit: The breadboard, generic component or developmental assembly of hardware and software that roughly performs the basic functions of the engineering unit, but is not fully functional equivalent. This unit is used for proof of concept testing of the preliminary design.

Engineering Unit: The hardware, firmware, and software unit that is functionally equivalent to the qualification unit, but not necessarily form and fit equivalent. This unit is used for proof of concept testing of the detailed design. It may be used for software verification credit after CDR with quality controls as defined in the Software Development Plan.

Design Verification Test Unit: (DVTU) The hardware, firmware, and software unit which is form, fit and functional equivalent to the flight unit, but may not be manufactured using the exact flight parts. This unit is used for design proof of concept.

Qualification Unit: A hardware, firmware and software unit which is identical to the flight unit in form, fit and function, as well as in manufacturing processes, parts, and quality control. This unit is used for verification and certification credit for all environmental requirements and performance requirements as needed.

Flight Unit: The hardware, firmware and software unit that is used operationally in the flight environment. This unit is designed and manufactured under strict quality control, with complete records of unit manufacturing, testing, shipping and handling.

Protoflight Unit: A flight unit used for qualification testing in lieu of a dedicated test article. This use of the flight unit for qualification testing often requires reduced test levels and/or duration and post-test hardware refurbishment where required.

Ground support equipment: All equipment (implements, tools, test equipment devices, simulations, etc.) required on the ground to support ground testing or training.